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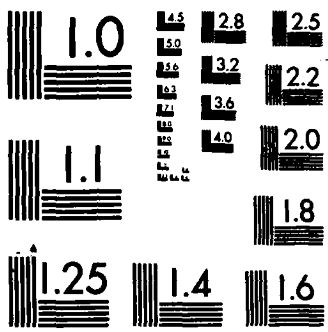

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STATISTICAL ANALYSIS OF ENERGETIC
ELECTRONS (1.2-16 MeV) AT
GEOSYNCHRONOUS ORBIT

THESIS

Douglas I. McCormick
Captain, USAF

AFIT/GSO/ENP-ENS/84D-1

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Wright-Patterson Air Force Base, Ohio

AFIT/GSO/ENP-ENS/84

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THESIS

Presented to the Faculty of the School of Engineering

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Space Operations

Douglas I. McCormick, B.A.

Captain, USAF

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Approved for public release; distribution unlimited

Preface

My own goals in this thesis effort were twofold. First, I hoped to further my knowledge of the near earth space environment. In this I believe I succeeded, but not without an increased humility from discovering how much I don't know. Second, I hoped to produce a product that was comprehensive and, at the same time, straightforward and direct. In particular, a study that anyone with some knowledge of the magnetosphere could readily examine and understand. Whether this was accomplished will have to be decided by the reader.

There are a number of people who helped in this effort and I deeply appreciate their patience and encouragement. First, of course, are my advisors, Major James Lange and Lieutenant Colonel Joseph Coleman. Major Lange provided invaluable guidance and direction in understanding physical processes at work in the space environment. Lieutenant Colonel Coleman assisted with computer operations and managed to teach some statistics to me, a miracle in itself. I would also like to thank Mr. John Franzen of the User Support Branch, Aeronautical Systems Division Computer Center. His assistance allowed successful transfer of raw data from tape to file. Finally, I would like to thank my wife, Cheryl, for her patience and support. I would not have been able to complete this thesis without her help.

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Abstract

This investigation examined the relationship between energetic electrons (1.2-16 MeV) at geosynchronous orbit and solar wind speed and Interplanetary Magnetic Field (IMF) effects. Electron flux data for a three year period, June 1979 to April 1982, came from DOD spacecraft 1979-053 in geosynchronous orbit. This data was compared statistically with solar wind and IMF data measured by other spacecraft located in the solar wind. Statistical techniques employed included graphical plotting, descriptive statistics, correlation analysis, analysis of variance, and discriminant analysis.

Results from this study used daily average values and indicate clear differences in behavior between 1.2 to 6.6 MeV electrons and 6.6 to 16 MeV electrons. Electron flux in the energy ranges of 1.2-1.8 MeV, 3.4-4.9 MeV, and 4.9-6.6 MeV showed generally strong correlation with each other. Electron flux in the energy ranges of 6.6-9.7 MeV and 9.7-16 MeV also showed strong correlation with each other, but not to the three lower energy channels. There was a weak positive correlation between electron flux below 6.6 MeV and solar wind speed, after one and a half to two days passage. There was a weaker, negative correlation between solar wind speed and electron

flux between 6.6 and 16 MeV. There was no meaningful correlation between electron flux at any energy level and IMF effects. These findings suggest that whatever processes affect electron fluctuations below 6.6 MeV are different from those for electrons above 6.6 MeV.

STATISTICAL ANALYSIS OF ENERGETIC ELECTRONS (1.2-16 MeV) AT GEOSYNCHRONOUS ORBIT

I. Introduction

Background

For over two decades the earth's magnetosphere and associated trapped charged particle populations have been the subject of much interest and study. Numerous scientific experiments have been conducted in an attempt to describe and explain magnetospheric processes. As a result of these efforts a great deal of detailed knowledge of the magnetospheric environment has emerged.

One particular area of study of the magnetosphere involves fluctuations of energetic charged particle (Van Allen belt) populations. The number of these particles can vary substantially. Causes for these fluctuations and sources for energetic particles remain under investigation. Many studies have focused on the contributions of the solar wind and the interplanetary magnetic field (IMF). In one, Baker et al. indicate that the dynamic behavior of the magnetosphere ". . . may be effectively discussed in terms of energy input from the solar wind into the magnetosphere" (Baker and others, 1982b:5917). In another study, Russell and others note that the interface between the solar wind and the magnetosphere is crucial ". . . since it is this interface which determines how much of the solar plasma and field energy is transferred to the earth's environment" (Russell and others, 1980:346). The direction of the IMF also plays an important role in magnetospheric conditions. Potemra indicates that ". . . considerable evidence exists from spacecraft measurements that conditions inside the magnetosphere are more active. . ." when the IMF is directed southward than when it points northward (Potemra, 1983:279).

The interest in magnetospheric conditions and the ability to predict changes in these conditions has grown as the near earth satellite population has grown. Many orbiting spacecraft operate in magnetospheric regions where charged particle fluxes can have significant effects. Collisions between energetic particles and satellites can, over a period of time, damage sensitive semi-conductor electronics and cause long-term degradation to satellite surface coatings. In addition, sudden bursts of charged particles can cause sudden changes in electrostatic charging of spacecraft which can induce transient electrical pulses. These pulses can damage electrical components and induce spacecraft operating anomalies. Furthermore, individual high energy electrons can produce spurious signalsdirectly if they impact appropriate electronic components.

The Department of Defense (DOD) has shown particular interest in energetic particle studies. U.S. Armed Forces are further describes an equation for total energy output rate of the magnetosphere as:

$$E = VB^2 \sin^4 \left(\frac{\theta}{2}\right) l_0{}^2$$

where V = solar wind velocity

B = solar wind magnetic field magnitude

θ = angle between normal to the ecliptic and B

$l_0 \simeq$ 7 earth radii

(Akasofu, 1983:176)

This approach differs from considering the magnetosphere as an "unloading" system where substorms occur from energy accumulated in the magnetosphere and released by some instability. Nishida indicates that "This interpretation seems open to question. . . ," and goes on to suggest that storage and release of energy does indeed seem to occur in the magnetotail. He also indicates, ". . . it is also possible that the reconnection involving the southward IMF is not the only way for supplying solar wind energy into the magnetosphere" and that other processes may be involved (Nishida, 1983:185-199). Even with this situation, Nishida concludes that it seems certain that the reconnection with the IMF is the dominant if not the only mode of energy transfer from the solar wind to the magnetosphere.

Most recently, Baker and others have studied the correlation between solar wind and IMF parameters and substorm activity using a spacecraft (in fact, ISEE3) in the

Crooker and others looked at six-month and yearly averages of solar wind speed and found high correlation with geomagnetic activity. Using the same time scale the southward component of the IMF and geomagnetic activity shows a poor correlation. They go on to suggest that the product of the southward component of the IMF and the square or higher power of the solar wind speed correlate well with geomagnetic activity independent of the time scale used (Crooker and others, 1977:1933-1936). Dessler and Hill commented on this study by indicating that the time derivative of solar wind speed could offer an explanation (Dessler and Hill, 1977: 5644).

Discussions to this point have emphasized the role that the IMF plays in coupling solar wind mass and energy into the magnetosphere. When the IMF points southward its field lines are thought to be reconnected to the earth's magnetic field and provide "openings" for the solar wind to penetrate into some magnetospheric regions. Hones describes another mechanism by which plasma and energy transfer may take place. This process involves ". . . direct (possible diffusive) entry of solar wind plasma into a magnetospheric boundary layer of closed magnetic flux tubes" (Hones, 1978:84).

Akasofu has recently indicated that the magnetosphere may be primarily a "driven" system and that the solar wind-magnetosphere interaction constitutes a "dynamo." Akasofu precondition for substorm occurrence. . . ," irregularities due to colliding solar wind streams (i.e., faster streams overtaking slower) also enhance the magnitude of resulting substorm activity (Garrett and others, 1974:4609). Burton and others indicate that

> An important feature of the transfer of energy into the magnetosphere is that it is not continuous but increases and decreases almost at random without accompanying changes in the kinetic energy of the solar wind (Burton and others, 1975:717).

They go on to provide experimental confirmation that the rate of energy transfer (measured by ring current) is proportional to the strength of the north-south IMF when the field is directed southward. Because the energy transfer rate is essentially zero when the IMF is directed north the magnetosphere thus acts as a "half wave rectifier."

Caan et al. investigated the characteristics of the association between the IMF and substorm. Among their findings were clear indications that magnetospheric substorms invariably ensued when the IMF shifted southward and remained southward for at least two hours following two hours of northward IMF. Their study goes on to indicate that energy dissipated during geomagnetic activity appears to come from reservoirs of stored magnetic energy in the magnetotail, and that the IMF may control the size of substorms by influencing the amount of stored tail flux available to be used (Caan and others, 1977:4837-4841).

accepted that the solar wind transfers mass, momentum, and energy to the magnetosphere. In addition, it is also generally agreed that geomagnetic activity in the form of storms and substorms is the most readily used phenomena to measure solar wind-magnetospheric interaction. Establishing the conditions necessary for increased or decreased solar wind-magnetosphere interaction has been the focus of most studies. Aubry and others first noted that the position of the magnetopause can vary significantly under apparently quiet solar wind conditions. This study also noted the change in the magnetopause position was associated with a reversal of the vertical (north-south) component of the IMF from north to south. This reversal also resulted in an erosion of magnetic flux in the daytime magnetosphere and an increased flux in the magnetotail (Aubry and others, 1970:7029-7030).

Further studies of magnetospheric storms and substorms sequences have continued to note the importance of the directionality of the IMF. McPherron and others indicate a southward turning of the IMF as part of the growth phase of a substorm (McPherron and others, 1973:3131). Russell and others indicate that a study of the solar wind and the IMF during four geomagnetic storms show that main phase developments are accompanied by strong southward IMF values (Russell and others, 1974:1108).

Garrett et al. take a slightly different approach. They note that while a southward IMF is the ". . . primary

II. Literature Review

Anyone conducting an investigation of energetic charged particle populations in the earth's magnetosphere will have a substantial amount of information to examine. Many books, journal articles and working group reports are available for scrutiny. In fact, magnetospheric studies have been underway since the first satellite observations of the radiation belts in 1958. The goal of early study efforts was the exploration and description of the near-earth magnetosphere environment. More recently, investigations have been aimed at understanding and explaining complex magnetospheric processes. Energetic particles in particular have been the subject of recent efforts. In fact, according to Spjeldvik and Rothwell,

> Precisely where radiation belt particles come from and how they are accelerated to energies in the keV and MeV range are still areas of research for which a comprehensive answer is not yet available (Spjeldvik and Rothwell, 1983:27).

Current literature concerning magnetospheric research and charged particle fluctuation in particular will be divided into two areas: Solar Wind-IMF-Magnetosphere Interaction and Energetic Particles.

Solar Wind-IMF-Magnetosphere Interaction

Solar wind and magnetospheric interaction has been and continues to be a much studied phenomena. It is generally and discriminant analysis will be used as necessary to assist in describing solar wind, IMF and energetic electron association.

daily electron measurements can be compared with previous 24-hour averages of solar wind and IMF data starting at any hourly point. Once data preparations are complete, inferential statistical analysis will begin.

This study follows another analysis of the same data in a recent thesis effort by another Air Force Institute of Technology (AFIT) student (Smith, 1983). Therefore, initial statistical efforts will focus on validation of results of that thesis. Very briefly, results obtained by Smith indicated a weak positive correlation between daily average electron count rates below 6.6 MeV and two-day old solar wind daily average velocities. There was essentially no correlation between these energetic electron count rates and the IMF B_z (north-south) component. (The IMF B_z component is normal to the solar ecliptic plane.) Upon validation, further statistical analysis will proceed. Specifically, inspection of the solar wind velocity correlation with electron count rate will be attempted for varying time delays. Solar wind velocity correlation with electron count rate enhancements will be examined for those cases where electron count rates exceed one standard deviation above the mean. IMF effects, particularly southward B_z component effects, will be further examined. Statistical analysis beyond this point will depend on correlation results. Regression analysis will be used to detail the relationship wherever a strong correlation exists. Analysis of variance to study the directional intensity of positive ions and electrons in the solar wind, transition region and magnetotail. H. S. Bridge from the Massachusetts Institute of Technology was the principal investigator for this experiment. ISEE 3 had two instruments for plasma study. Ion velocity distributions were measured by a 135 degree spherical electrostatic analyzer. Electron velocity distributions were measured by a 90 degree spherical electrostatic analyzer. S. J. Bame from the Los Alamos Scientific Laboratory directed this experiment. When both IMP and ISEE plasma data were available for a given period, IMP data were used. This was due to IMP's closer proximity to the earth. All solar wind velocities were available in one-hour averages.

Methodology

The first step will be to prepare solar wind and IMF data into daily averages. Once this is complete, graphical plots of respective electron, solar wind, and IMF values will be constructed. This will allow visual inspection to determine data behavior and distribution. Descriptive statistics including mean, standard deviation, and maximum and minimum values will also be calculated. The next step will be to prepare solar wind and IMF data for comparison with electron channel daily averages. Part of this preparation includes assuring that electron averages are in chronological order with the appropriate solar wind and IMF averages. Since solar wind and IMF data is available in hourly averages, 12.5 day geocentric orbit. This orbit had the spacecraft in the solar wind from six to eight days per orbit.

ISEE 3 was instrumented to study the outer magnetosphere. The data collected from ISEE 3 for this study occurred while the spacecraft was in a heliocentric orbit about the sunward libration point. This orbit put ISEE 3 in the solar wind "upstream" from the earth and allowed the spacecraft to observe the solar wind about an hour before it reached the outer magnetosphere.

Very nearly all of the IMF data used in this study came from the IMP 8 spacecraft. Only a few days of IMF measurements came from ISEE 3. The IMF sensor on board IMP 8 consisted of a boom-mounted triaxial fluxgate magnetometer designed to study the geomagnetic tail magnetic fields. Each of these sensors operated in the range of plus or minus 36 nanotesla during the study period. A typical value of the IMF is 5 nanotesla. The principal investigator for the IMP 8 magnetometer was N.F. Ness from NASA Goddard Space Flight Center. ISEE 3 used a boom mounted, triaxial vector hellium magnetometer. This experiment was under direction from E. J. Smith from the Jet Propulsion Laboratory. IMF data from ISEE 3 was not available after June 1979. All IMF data was available in one-hour averages.

Solar wind measurements on both spacecraft are based on ion and electron measurements. IMP 8 instrumentation consisted of a modulated split-collector Faraday cup, perpendicular to the spacecraft spin axis. This device was used nearly all pitch angles would be sampled by HiE, but for nondipolar (taillike) magnetic field configurations often encountered near midnight at $6.6R_e$, very limited pitch angle sampling can result. The HiE has a relatively thick aluminized mylar window immediately in front of the sensitive solid state detector elements. This eliminates contamination by sunlight, very low energy (< 10 kev) electrons, and by protons below 250 to 300 kev.

Data from the SEE sensor is acquired in four separate channels between 3.4 and 16 MeV. The SEE sensor combines thick solid state (dE/dx) detector elements with a bismuth germanate scintillator (total E) element to provide electron measurements. Measurements are made with a large geometric factor (.15 square centimeters-steradian).

Electron data from all energy channels are in daily averages.

Both solar wind velocity and IMF data were obtained from the National Space Science Data Center (NSSDC). This data comes from both the IMP 8 and ISEE 3 spacecrafts. Once again, spacecraft parameters and instrumentation have already been described (Rosenvinge, 1982:1-9; King, 1982:10-20). These descriptions are reproduced here.

IMP 8 was designed for magnetotail and interplanetary studies of cosmic rays, energetic solar particles, plasma, and electric and magnetic fields. At the time the data was collected for this study, IMP 8 was in a low eccentricity,

Data

The energetic electron data for this study came from instruments on board geosynchronous spacecraft 1979-053. This data was made available through the Los Alamos Scientific Laboratory. Baker and others have already described spacecraft parameters and instrumentation (Baker and others, 1982a: 83). For completeness, this description will be reproduced here.

Subsequent to June 1979 spacecraft 1979-053 was positioned at 135° W. This spacecraft rotates about an axis continually pointed toward the center of the earth. Each rotation takes ten seconds. Two detector packages on board the spacecraft collected the electron data used on this study. Electron data from 1.2 to 1.8 MeV was acquired from a high energy electron (HiE) detector as part of Charged Particle Analyzer instrumentation. Electron data from 3.4 to 16 MeV was from the Spectrometer for Extended Electron measurements (SEE).

The HiE detector consists of a single detector-collimator unit that is pointed radially outward in the spacecraft equatorial plane (0°). The HiE detector geometric factor is .018 square centimeter-steradian. A relatively narrow band of the unit sphere is sampled as the spacecraft rotates. This results from the single collimator unit (half angle of acceptance approximately four degrees) that is used. For normal, approximately dipolar magnetic field orientations

1-2 MeV. Relatively few investigations have involved energy levels above 2 MeV. Correlation between high-energy electron (below 2 MeV) increases at geosynchronous orbit and solar wind velocity has already been shown. However, causes for increases in electron flux above 2 MeV is less certain. There is some evidence that these increases may be tied to two-day old solar wind values. (See Literature Review.)

Objectives of the Research

The objective of this research will be to attempt to identify the source or sources of large increases in high energy (1.2 to 16 MeV) electron channels observed at geosynchronous orbit. More precisely, this research will attempt to show a possible correlation between the solar wind and IMF and these high energy electron levels. In addition, investigation of IMF data will be attempted to determine if IMF modulation of galactic cosmic rays could indicate a source of these observed energetic electrons. The ultimate objective of this research is to determine if a prediction capability can be developed for energetic electron fluctuations in the magnetosphere. This predictive capability would be based on the strength of correlation between source and electron variations. The scope of this study will be restricted to the data provided by satellite 1979-053 between June 1979 and April 1982, and electron energy levels between 1.2 MeV and 16 MeV.

enough different points to truly understand the complex relationships between its different parts" (Baker and others, 1982b:5917). Specifically, it is not a trivial task to position enough spacecraft with appropriate sensors at enough different locations in the magnetosphere and solar wind to measure statistically significant data. The magnetosphere is very dynamic and constantly changes its characteristics, shape, and size, and most satellites in their orbital paths continually change their positions relative to the magnetosphere.

Frequent observations of energetic particle fluxes come from satellites located in geosynchronous orbits. In a geosynchronous orbit, a satellite appears to stay fixed over one point on the earth's equator. As the earth turns, the satellite remains "overhead" in generally the same position. The geosynchronous orbit position is important for two reasons. First, many communications, weather, and surveillance type spacecraft reside there. Second, scientific instruments at these altitudes can probe both the outer trapped radiation region and the magnetotail plasma sheet (Baker and others, 1982a:82). Both of these regions are important to understanding magnetospheric processes.

Energetic particle studies are usually based according to particle type (i.e., proton, electron, etc.), energy level, and angular distribution. Many energetic electron investigations to date have involved energy levels below heavily dependent on satellites for communications, meteorology, navigation, and surveillance. Many DOD spacecraft reside and operate in regions dominated by the Van Allen belts. As described earlier, these satellites are subject to possible damage or degradation from energetic Van Allen particles. For example, Defense Meteorological Satellite Program satellites commonly experience attitude control sensor upsets due to energetic particle effects (Jochum, 1984). A particular example of Air Force interest and concern is a recent draft Statement of Need (SON) from Military Airlift Command (MAC) to Headquarters USAF stating that manned space activities and electronic systems on satellites are vulnerable to energetic charged particles confined by the earth's magnetic field. The SON goes on to state that because of this concern, improved space environmental monitoring is necessary for more accurate forecasts of environmental conditions. Specifically, ". . . observations of charged particle densities from several altitudes are needed to adequately determine the environments in which manned vehicles as well as DOD satellites operate" (MAC SON 01-83, 1983).

The difficulty to studying the magnetosphere should not be underestimated. In addition to the subject itself, Baker and others note that because of the vast distances involved, ". . . within the magnetosphere, it has been a very difficult problem to probe the system concurrently at upstream solar wind. This was in an attempt to evaluate how well a satellite could act as a real time monitor to predict substorms and measure solar wind energy input into the magnetosphere. General results were guarded with indications that a spacecraft in a distant upstream position can, ". . . under most conditions, be a very useful platform for monitoring magnetospheric energy input" (Baker and others, 1983:6241).

Finally, Burch has recently provided an in-depth review concerning progress on magnetospheric energy transfer. It is important to note that he indicates:

> In spite of the impressive correlations that have been found between solar wind parameters and various geomagnetic indices, there is still no accepted model of the role of the solar wind in individual substorms (Burch, 1983:463).

Energetic Particles

Protons, electrons, and heavy ions make up the energetic particle populations trapped in the magnetosphere. Particle energies for electrons and protons range from just a few eV up to MeV for electrons and several hundreds of MeV for protons. It is commonly agreed that there are stably trapped regions (radiation belts) of relatively constant fluxes in the magnetosphere. An "inner zone" of energetic (> 30 MeV) proton flux is located between 1.5 and 2.5 earth radii. Electron populations are generally grouped into both inner and outer zones. Inner zone electrons (> .5 MeV) are in about the same region as inner zone protons. Outer zone electrons (> 40 keV) range from 3.5 up to six earth radii and even farther depending on flux and energy level observed. Of course, it should be noted that a thorough description of particle populations is much more complex and depends on flux and energy level, spatial position, etc. As a matter of interest, empirical models of trapped particle environments are available for both electrons and proton zones (Spjeldvik and Rothwell, 1983:71-104).

The outer electron zone has distinct differences from the inner zone. The outer zone is much more dynamic. Electron and proton flux levels can change significantly within minutes. In addition, electrons have a relatively short residence time.

Arnoldy and Chan noted charged particle intensity fluctuations over fifteen years ago. They observed that a magnetic substorm produced new electrons of energy > 50 keV very near the midnight medridian as observed at 6.6 earth radii (geosynchronous orbit). Also, magnetic substorm generation of this type appeared to be a frequent source of particles for the outer zone (Arnoldy and Chan, 1969:5019).

Bogott and Mozer established that major decreases of proton and electron fluxes (at energy levels below 1 MeV) at geosynchronous orbit often precede substorm expansion. These particle decreases were in terms of inward motion of the nightside magnetosphere trapping boundary (Bogott and Mozer, 1973:8119-8126).

In 1978, Pellinen and Heikkila noted that in several other studies, observations had been made of bursts of energetic particles, both protons and electrons, with energies above 1 MeV. These bursts had been generally associated with magnetospheric substorm activity. They theorize that particles with these type of energy levels ". . . can be produced with electric and magnetic fields of the magnitude found in the magnetotail" (Pellinen and Heikkila, 1978:1549).

In an empirical study intended for use as a general reference for spacecraft designed to operate a geosynchronous orbit, Su and Konradi have noted relevant energetic particle particulars. They indicate that for energy ranges between 50 eV and 50 keV, electron flux intensities were higher than protons at all times. Further, the proton flux intensity increased by a maximum of a factor of 20, whereas electron flux intensities increased by a factor of 750 and were in accordance with geomagnetic activities (Su and Konradi, 1978: 25).

Baker and others studied charged particle (including high energy proton) increases at geosynchronous orbit and concluded with varied results. Specifically, only about 10-20 percent of all substorms are accompanied by > .3 MeV proton increases. However, they also note, ". . . virtually all substorms are accompanied by some observable injection of electrons with energies > 30 keV, and most substorms are accompanied by increased fluxes of protons with energies > 145 keV" (Baker and others, 1979:7138-7152). Their study goes on to demonstrate that > .4 MeV proton and > .2 MeV electron intensities tracked solar wind velocities closely and that high energy substorm-accelerated particles occur preferentially when the solar wind is high (greater than 400 km/sec). In addition, these proton enhancements had a noticeable tendency to occur when the IMF was directed southward.

A study that is especially significant to this research was made by Paulikas and Blake. Energetic electrons at synchronous orbit were compared to solar wind values. Results indicated that very approximately (underlined by the study) about a day is needed to generate 140-600 keV electrons and two days are required to generate > 3.9 MeV electrons. Further, the

> . . . differences in time required by the various electron energy channels to respond to changes in the solar wind can be taken to be a measure of the time the magnetosphere requires to generate energetic electrons and to transport these particles to the synchronous orbit (Paulikas and Blake, 1978:15-16).

Paulikas and Blake further state that the picture that emerges is one where the solar wind velocity is the most important parameter in organizing electron flux levels with the B_z component of the IMF modulating the efficiency of the solar wind velocity as a "generator" of energetic electron events.

Baker and others coordinated data from eleven widely separated spacecraft to observe energetic particles at geosynchronous orbit. This, of course, offered the advantage of observing the magnetosphere at several points all at once. The results presented indicated that, for the specific day observed, the magnetosphere went through a period of substantial energy storage prior to a sudden energy release. This energy storage was interpreted as a ". . . taillike change of magnetic topology at 6.6 R_e" (Baker and others, 1982b:5931). Flux "dropout" near local midnight and subsequent recovery and injection of substorm particles were also observed.

In another study, Baker and others have recently summarized energetic electron and proton measurements made by Los Alamos National Laboratory. These sensors are on spacecraft at geosynchronous orbit. The summaries are available through the <u>Los Alamos Synchronous Data Set</u>. Energetic electron flux behavior at 6.6 earth radii is specifically addressed with notable results. Daily averages of electron flux for both 200 to 300 keV and 1.4 to 2.0 MeV electrons are clearly correlated to solar wind velocities. It is particularly noteworthy that the flux modulation for the higher energy (1.4 to 2.0 MeV) electrons is much larger than the 200 to 300 keV electrons. This flux increase is also delayed by a few days following peak solar wind velocities (Baker and others, 1982a:87). These results are similar to Paulikas and Blake.

Two recent publications are noted to conclude this area. Young has compiled a review of near-equatorial magnetospheric particles. This report is particularly detailed and suggests a schematic relationship of magnetospheric particle populations (Young, 1983:402-414).

Finally, a report on the earth's radiation belts by Spjeldvik and Rothwell has been especially useful to this author. Charged particle fundamentals are described and a succinct summary of possible sources for energetic charged particles is provided (Spjeldvik and Rothwell, 1983:13-31).

This literature review is certainly not comprehensive. Quite a number of other articles exist in the literature concerning solar wind-magnetosphere interaction and energetic charged particle behavior. However, it is hoped that this review is representative of the type of reports that are available and covers many of the more important ones.

III. Data Preparation and Statistical Measures

Processing Equipment and Statistical Software

The computer system used in this study was a CDC Cyber 6000. During the study the Cyber was located at the Aeronautical Systems Division (ASD) Computer Center on Wright-Patterson AFB, Ohio. The Cyber was chosen because of its ready availability to AFIT students and its preeminent processing capability among the computer systems available. The statistical software used was a version of the Statistical Package for the Social Sciences (SPSS) (Nie and others, 1975). This version was developed by the Vogelback Computing Center of Northwestern University. SPSS was used primarily because of its extensive use at AFIT. SPSS programs were well documented and straightforward to employ.

Data Preparation

Data preparation for this investigation took two main steps. The first involved retrieving the raw electron, solar wind, and IMF data off the magnetic tapes provided by Los Alamos and NSSDC. This data was written into appropriate files on the Cyber. The second step involved combining both data files into one time synchronized file that could be accessed by SPSS.

The energetic electron data (from Los Alamos) was stored on a magnetic tape generated by a CDC computer similar to the one at AFIT. This data was arranged in chronological order according to energy channel. The respective energy channels were 1.2 - 1.8 MeV, 3.4 - 4.9 MeV, 4.9 - 6.6 MeV, 6.6 - 9.7 MeV, and 9.7 to 16 MeV.

Extraction of solar wind and IMF data from the NSSDC tape was more difficult. This tape contained a very large data bank and was generated on an IBM 360/75 system. Geomagnetic and sunspot data was available in addition to solar wind and IMF data. With the aid of the user support division of the ASD Computer Center, this obstacle was overcome. Solar wind and IMF hourly averages were read onto file on the Cyber where they were summed over daily 24-hour periods and averaged. It should be noted that all 24 hours of data had to be missing before a daily average value would be declared missing. For example, if only three hourly averages were available for the 24-hour period, then these three were averaged for the daily average.

After the electron and solar wind/IMF files were generated they were combined into a single file containing all available data. This allowed SPSS processing for statistical analysis. During the course of the study, the combined file was further adjusted to allow analysis of electron response to solar wind/IMF variations using different time delays. As described earlier, this allowed daily electron measurements to be compared with previous 24-hour averages of solar wind and IMF values starting at any hourly point. Further, missing (zero) values were identified for proper SPSS processing.

Because correlation analysis is integral to the statistical effort in this project, a short discussion of appropriate statistical measures is provided.

Correlation Analysis

Correlation analysis is the focus of the statistical effort in this project. Specifically, do fluctuations in the solar wind and/or the IMF correspond to energetic electron fluctuations in the energy channels studied? In addition, if such a relationship exists, how strong is it and can we use it for prediction purposes? Two statistical measures are frequently used to provide this information. They are: R, the coefficient of correlation; and R^2, the coefficient of determination. R is used as an indicator of the goodness of fit of a linear regression. Further, ". . . it is a measure of association indicating the strength of the linear relationship between the two variables" (Nie and others, 1975:279). R can take on values between negative one and one. Values of one and negative one indicate a perfect linear fit. Positive values indicate a positive correlation. That is, one variable increases as the other variable increases. Negative values denote an inverse relationship. As one variable goes up, the other variable goes down. R values close to zero indicate a poor linear relationship. In particular, an R of zero would show a complete absence of a linear relationship.

R^2 provides the other important statistic. Nie and others indicate that ". . . R^2 is a more easily interpreted measure of association when our concern is with strength of relationship rather than direction of relationship." Further, "Its usefulness derives from the fact that R^2 is a measure of the proportion of variance in one variable 'explained' by the other" (Nie and others, 1975:279). R^2 is defined as:

$$R^2 = \frac{\text{Total variation} - \text{Residual variation}}{\text{Total variation}}$$

where total variation is the original variation of all data and residual variation is ". . . the amount of the original (total) variance which cannot be explained by using the regression line as a prediction device" (Nie and others, 1975:280). R^2 takes on values between zero and one. Neter and Wasserman point out ". . . we may interpret R^2 as the proportionate reduction of total variation associated with the use of the independent variable. . . ." (Neter and Wasserman, 1974:89). Thus, the larger is R^2, the more the total variation of the dependent variable will be reduced by introducing the independent variable. Precisely, R^2 values close to one indicate a great degree of association between independent and dependent variables. R^2 values close to zero indicate no association.

ANOVA

Analysis of Variance (ANOVA) is another statistical inference tool that may be used for studying the relation between independent and dependent variables. ANOVA is particularly useful because no assumption is necessary concerning the nature of the relationship between variables. Neter and Wasserman state "Thus, the problem of specifying the type of regression function, encountered in ordinary regression analysis, does not arise in analysis of variance models" (Neter and Wasserman, 1974:420). Essentially then, ANOVA provides a means of investigating whether any relationship exists as opposed to a specific type such as linear, exponential, etc.

ANOVA is based on decomposition of sums of squares and degrees of freedom associated with the dependent variable. For one-way ANOVA, the independent variable (known as a factor) is first organized into categories or levels. Then, the total sum of squares (the variation of all observations from the overall mean) can be partitioned into the sum of two independent components. The first component is the portion of the sum of squares in the dependent variable due to the factor under analysis. This is precisely equal to the sum of the squared differences of the factor level means from the overall mean. This sum is commonly referred to as SSTR, for Sum of Squares for Treatment. A treatment is a particular combination of factor levels (Mendenhall and others, 1981:484). The second component is the portion of the sum of squares due to variation within each factor level. This is the deviation of the observations around the mean of the particular factor level. This sum is customarily known as SSE, for Sum of Squares for Error. In summary,

$$\text{Total Sum of Squares} = \text{SSTR} + \text{SSE}$$

The statistic used to measure the strength of effects of the independent variable on the dependent variable is, again, R^2.

$$R^2 = \frac{\text{Total Sum of Squares-SSE}}{\text{Total Sum of Squares}} = \frac{\text{SSTR}}{\text{Total Sum of Squares}}$$

From this definition it can be seen that independent variable effects depend on the degree of variability of the data as a whole and on the variability within each factor level (Nie and others, 1975:401). Once more, R^2 values run between zero and one. R^2 values close to one indicate there is little variability within each factor level and some variability between levels. Values close to zero indicate essentially no difference between factor level means.

In addition to R^2, the traditional F test is applied with ANOVA and correlation analysis. Using appropriate sums of squares divided by respective degrees of freedom (mean squares), the F test is used to check agreement or disagreement with the "null hypothesis." That is, are the means for each factor level the same? Mendenhall and others indicate, "Disagreement with the null hypothesis is indicated by a large value of F. . ." (Mendenhall and others, 1981:509). Statistical significance levels will also be provided with F-test values. Significance levels indicate the probability of rejecting the null hypothesis when it is true (Mendenhall and others, 1981: 374,390).

This author found discussions in Neter and Wasserman to be particularly helpful (see sections 3.8 and 13.1). The reader is encouraged to consult this reference for a rigorous treatment.

Discriminant Analysis

Discriminant analysis is another statistical tool that may be employed. Very briefly, discriminant analysis attempts to ". . . statistically distinguish between two or more groups of cases" (Nie and others, 1975:435). Integral to discriminant analysis is determining "What role do the variables for which measurements have been obtained play in separating the groups?" (McNichols, 1980:7-3). McNichols goes on to say that a linear function called a discriminant function can be constructed. The discriminant function is formed by one or more linear combinations of variables. In addition, discriminant functions are formed so as to maximize between group separation (Nie and others, 1975:435). By examining the discriminant function, the variables most important in separating the groups can be determined. Once derived, discriminant functions allow analysis and classification of groups.

IV. Results

Data Examination

Graphical plots of electron count rates, solar wind velocity, and IMF B_z values portray data behavior and variability. All values are plotted against days beginning with June 13, 1979. Electron count rates or flux are measured in counts/sec, solar wind values in km/sec, and IMF B_z values are measured in gammas (10^{-9} tesla). Each graph has one hundred days worth of data. Figure 1 is provided as a representative sample. This graph depicts the daily count rate for the 1.2 to 1.8 MeV electron channel between June 13, 1979 and September 20, 1979. All other graphs may be found in the Appendix.

Electron fluxes for the 1.2 to 1.8 MeV electron channel vary quite a bit over the entire period. Large changes occur pretty much at random with no readily apparent pattern. Maximum fluctuations are approximately one to two orders of magnitude. Inspection of the 3.4 to 4.9 MeV and 4.9 to 6.6 MeV channels show count rate fluctuations notably similar to the 1.2 to 1.8 MeV channel on a much smaller scale. This similarity is stronger for the 3.4 to 4.9 MeV electrons. In addition, the relative magnitudes of the fluctuations are stronger for the 3.4 to 4.9 MeV channel. Only two events show changes approaching an order of magnitude in the 4.9 to 6.6 MeV channel. Most other significant flux changes are

TABLE IV

CORRELATION ANALYSIS RESULTS

Electron Data One Standard Deviation Above Mean Value			
	R	R^2	Significance
1.2-1.8 MeV electron flux			
with current solar wind speed	0.151 (0.217)	0.023 (0.047)	.075*
with 1 day old solar wind speed	0.344 (0.427)	0.118 (0.182)	.001
with 2 day old solar wind speed	0.471 (0.508)	0.222 (0.258)	.001
with 3 day old solar wind speed	0.415 (0.437)	0.172 (0.191)	.001
3.4-4.9 MeV electron flux			
with current solar wind speed	0.196 (0.238)	0.038 (0.057)	.082*
with 1 day old solar wind speed	0.279 (0.366)	0.078 (0.134)	.030
with 2 day old solar wind speed	0.219 (0.414)	0.048 (0.171)	.079*
with 3 day old solar wind speed	0.135 (0.357)	0.018 (0.127)	.192*
4.9-6.6 MeV electron flux			
with current solar wind speed	0.137 (0.197)	0.018 (0.039)	.194*
with 1 day old solar wind speed	0.187 (0.280)	0.035 (0.078)	.138*
with 2 day old solar wind speed	0.127 (0.288)	0.016 (0.083)	.233*
with 3 day old solar wind speed	-0.007 (0.226)	0.000 (0.051)	.484*

drive corresponding energetic electron behavior. Perhaps solar wind enhancements of some magnitude are necessary before electron behavior is affected. Once again, solar wind values were staggered. This time only full one-, two-, and three-day old solar wind values were included. These results are shown in Table IV. R^2 values for all channels were generally small and several cases were not statistically significant. R^2 for the 1.2 to 1.8 MeV channel showed, very generally, the same type of results as with all data. However, the highest values was 0.222 (P = .001) with two-day old solar wind. This is even weaker than earlier results. The two highest channels did show positive type correlation instead of negative. Even so, only weak correlations were indicated.

Correlation values for electron events over two standard deviations above the mean are not provided. These results were calculated but the limited number of instances generated would have made any statistical inferences questionable. For example, the 9.7 to 16 MeV channel generated only seven cases where electron flux exceeded two standard deviations above the mean.

Correlation results were also obtained to investigate the influence of the IMF B_z component. Electron flux was again correlated against staggered solar wind values, but this time only for days where B_z was negative. On the whole, results were inconclusive, yet some differences were indicated (see Table V). The 1.2 to 1.8 MeV channel showed very slight occurred with one and a half day old solar wind. R^2 with two-day old solar wind was 0.258 ($P = .001$). This indicates that only about 26% of the variation in electron count rates can be explained by solar wind values that are 36 to 48 hours old. R^2 values for the 3.4 to 4.9 MeV and 4.9 to 6.6 MeV channels were even weaker. In spite of this, these channels showed the same trends as the 1.2 to 1.8 MeV channel. Each had their highest R^2 values with either one and a half or two-day old solar wind values. The 3.4 to 4.9 MeV channel had an R^2 of 0.171 ($P = .001$) with two-day old solar wind, and the 4.9 to 6.6 MeV channel had an R^2 of 0.091 ($P = .001$) with day and a half old solar wind.

For the most part, the two highest energy channels had smaller R^2 values than the three lower energy channels. However, unlike the three lowest energy channels, both the 6.6 to 9.7 MeV and the 9.7 to 16 MeV electron channels show inverse relationships with solar wind. All relationships were negatively correlated. The largest R^2 values for both channels comes with current day solar wind values. It is apparent that even though correlation indicators are very weak, there is, again, a noticeable difference in behavior between the three lowest energy channels and the two highest.

The next investigation for possible correlation excluded electron data points below one and two standard deviations above the mean. This is compatible physically to the notion that day-to-day solar wind fluctuation may not

TABLE III--Continued

	R	R^2	Significance (P)
9.17-16 MeV electron flux			
with current solar wind speed	-0.319	0.102*	.001
with ½ day old solar wind speed	-0.280	0.078	.001
with 1 day old solar wind speed	-0.256	0.066*	.001
with 1½ day old solar wind speed	-0.229	0.052	.001
with 2 day old solar wind speed	-0.228	0.052*	.001
with 2½ day old solar wind speed	-0.191	0.036	.001
with 3 day old solar wind speed	-0.195	0.038*	.001
with IMF B_z Component	0.006	0.000*	.439**

*Denotes values confirmed in earlier study by Smith (1983)

**Denotes values having no statistical significance

TABLE III--Continued

	R	R^2	Significance (P)
4.9-6.6 MeV electron flux			
with current solar wind speed	0.197	0.039*	.001
with ½ day old solar wind speed	0.241	0.058	.001
with 1 day old solar wind speed	0.280	0.078*	.001
with 1½ day old solar wind speed	0.302	0.091	.001
with 2 day old solar wind speed	0.288	0.083*	.001
with 2½ day old solar wind speed	0.264	0.069	.001
with 3 day old solar wind speed	0.226	0.051*	.001
with IMF B_z Component	0.001	0.000*	.494**
6.6-9.7 MeV electron flux			
with current solar wind speed	-0.199	0.040*	.001
with ½ day old solar wind speed	-0.175	0.030	.001
with 1 day old solar wind speed	-0.150	0.022*	.001
with 1½ day old solar wind speed	-0.129	0.017	.001
with 2 day old solar wind speed	-0.137	0.019*	.001
with 2½ day old solar wind speed	-0.122	0.015	.001
with 3 day old solar wind speed	-0.133	0.018*	.001
with IMF B_z Component	0.015	0.000*	.356**

TABLE III

CORRELATION ANALYSIS RESULTS

	R	R^2	Significance (P)
<u>1.2-1.8 MeV electron flux</u>			
with current solar wind speed	0.217	0.047*	.001
with ½ day old solar wind speed	0.344	0.118	.001
with 1 day old solar wind speed	0.427	0.182*	.001
with 1½ day old solar wind speed	0.511	0.261	.001
with 2 day old solar wind speed	0.508	0.258*	.001
with 2½ day old solar wind speed	0.490	0.240	.001
with 3 day old solar wind speed	0.437	0.191*	.001
with IMF B_z Component	-0.109	0.012*	.003
<u>3.4-4.9 MeV electron flux</u>			
with current solar wind speed	0.238	0.057*	.001
with ½ day old solar wind speed	0.309	0.095	.001
with 1 day old solar wind speed	0.366	0.134*	.001
with 1½ day old solar wind speed	0.408	0.166	.001
with 2 day old solar wind speed	0.414	0.171*	.001
with 2½ day old solar wind speed	0.406	0.165	.001
with 3 day old solar wind speed	0.357	0.127*	.001
with IMF B_z Component	-0.040	0.002*	.161**

might include data plots (scatter plots) for visual indications and correlation and discriminant analysis as appropriate. However, because of the nature of this analysis, that pattern was not precisely followed. As noted earlier, this work follows analysis of the same data in a thesis effort by another AFIT student. This provided, in effect, a basis of "starting point." For that reason, initial efforts involved regeneration of the results in that thesis, accompanied by further analysis. Therefore, the results of correlation analysis and ANOVA will be presented first, followed by discriminant analysis results. The reader may refer to results by Smith (Smith, 1983) for scatter plot diagrams. Results that were reproduced are appropriately indicated.

Correlation Analysis

Calculation of R^2 values for all five electron energy channels with current and staggered solar wind values produced weak correlations that were statistically significant ($P < 0.05$). Nearly all pairings of electron count rates with IMF B_z showed no statistical significant ($P > 0.05$). Results of R, R^2 and corresponding significance for each energy channel are shown in Table III.

Solar wind values were staggered to daily electron count rates by half days up to three full days. The lowest energy channel, 1.2 to 1.8 MeV electrons, showed the highest correlations to solar wind parameters. Even so, the highest R^2 value for this channel was only 0.261 ($P = .001$). This

TABLE II

DESCRIPTIVE STATISTICS

1.2-1.8 MeV electron flux

Mean: 222.6
Standard Deviation: 263.4
Minimum: 2.79
Maximum: 1650.78

3.4-4.9 MeV electron flux

Mean: 0.431
Standard Deviation: 0.838
Minimum: 0.05
Maximum: 9.24

4.9-6.6 MeV electron flux

Mean: 0.076
Standard Deviation: 0.057
Minimum: 0.044
Maximum: 0.730

6.6-9.7 MeV electron flux

Mean: 0.116
Standard Deviation: 0.020
Minimum: 0.080
Maximum: 0.370

9.7-16 MeV electron flux

Mean: 0.223
Standard Deviation: 0.033
Minimum: 0.150
Maximum: 0.630

Solar Wind Speed

Units: km/sec

Mean: 410.310
Standard Deviation: 79.80
Minimum: 283.1
Maximum: 808.3

IMF B_z Component

Units: gammas

Mean: -0.043
Standard Deviation: 2.39
Minimum: -10.1
Maximum: 14.0

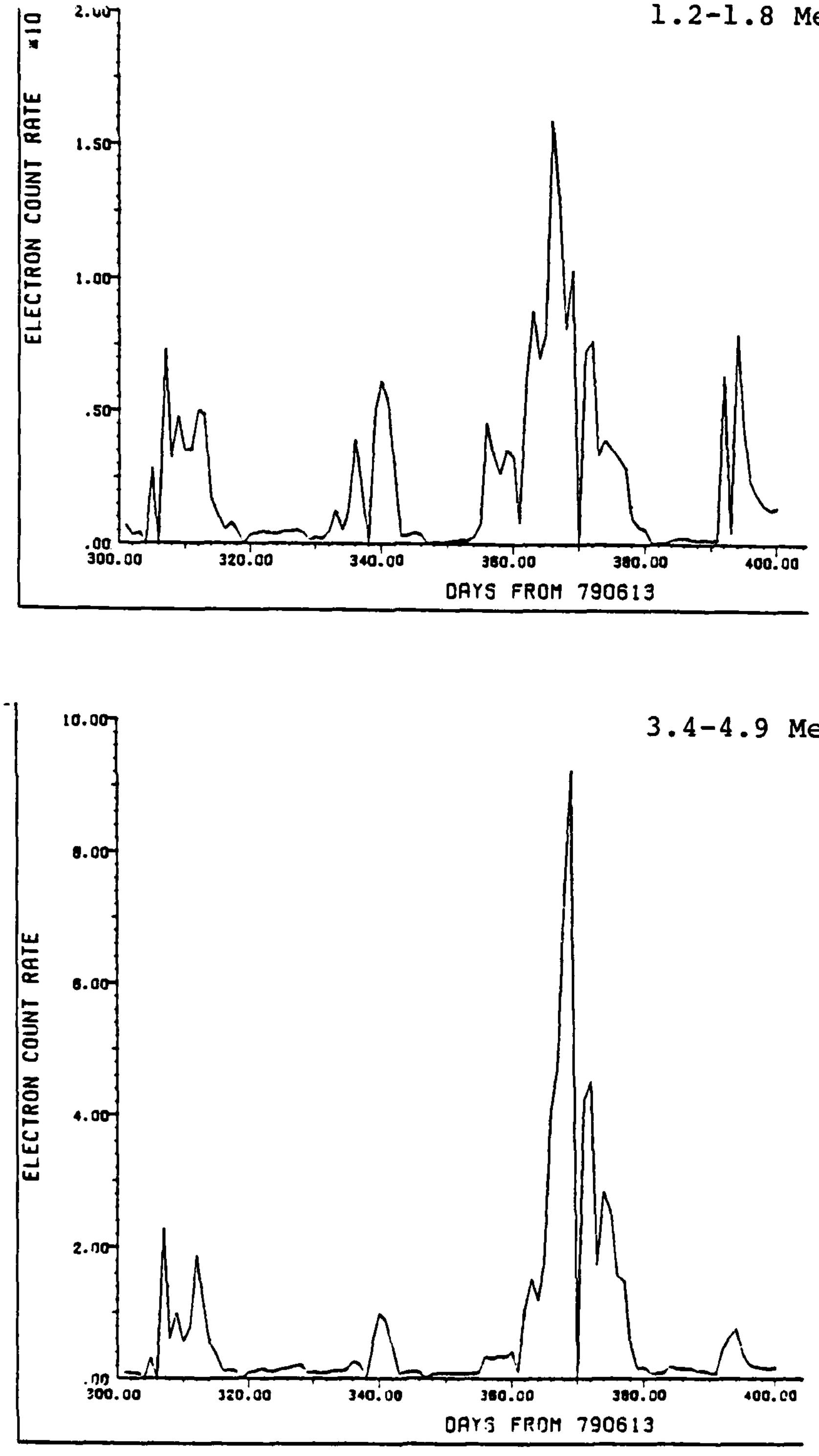


Figure 2. Electron Flux Comparison

An illustration is provided in Figure 2. This shows similar behavior in the 1.2 to 1.8 MeV and 3.4 to 4.9 MeV channels between April 8, 1980 and July 16, 1980.

Examination of solar wind velocities during the study period provides no surprises. Values vary randomly with the majority falling between 300 and 600 km/sec. IMF fluctuations were similar in that no discernible pattern was evident. Negative IMF values indicate a southward pointing field. Magnitude changes in both solar wind and IMF B_z values were, for the most part, less than a factor of two. Very rarely, changes up to factors of three or four occurred.

Descriptive Statistics

Descriptive statistics, including mean, standard deviation, and maximum and minimum values are provided for all parameters in Table II. These values confirm what the graphs pictorially presented. Large standard deviation values for the 1.2 to 1.8 MeV, 3.4 to 4.9 MeV, and 4.9 to 6.6 MeV channels indicate their variability. The standard deviation for all three lower energy channels is at least 0.75 of the mean value, and in the case of the 3.4 to 4.9 MeV channel the standard deviation is nearly double the mean value. On the other hand, small standard deviation values for the two highest channels suggest their overall stability in the study period.

Before proceeding further, some clarification is necessary. A "normal" progression of statistical analysis lowest energy channels do indeed have similar behavior. About 54% (correlation coefficient of .736) of the variation in the 3.4 to 4.9 MeV channel and about 26% (correlation coefficient of .506) of the variation in the 4.9 to 6.6 MeV channel correlate with the behavior in the 1.2 to 1.8 MeV channel. Further, almost 80% of the variation in the 4.9 to 6.6 MeV channel correlate with changes in the 3.4 to 4.9 MeV channel. In contrast, there is very little correlation between any of the three lower energy channels and the two highest energy channels. For example, the strongest correlation (between the 4.9 to 6.6 MeV and the 6.6 to 9.7 MeV channels) is only about 15%. All other correlations are below 5%. However, there is a very strong association between the 6.6 to 9.7 MeV and 9.6 to 16 MeV channels. In particular, over 83% of the fluctuations in the 9.7 to 16 MeV channel are correlated with those in 6.6 to 9.7 MeV electron behavior.

In summary, it appears that the count rates in the three lowest energy channels have roughly similar behavior and are being caused by the same processes. The two highest energy channels are closely correlated to each other but not with the lower three. This would seem to indicate the processes or sources of fluctuations in the two highest channels are different from those in the lower energy electron channels. A very effective means to visualize these correlations is to line up all channels, one below the other, time synchronized.

TABLE I

CORRELATION COEFFICIENTS (R) FOR ELECTRON CHANNEL FLUXES

Channel	1.2-1.8 MeV	3.4-4.9 MeV	4.9-6.6 MeV	6.6-9.7 MeV	9.7-16 MeV
1.2 - 1.8 MeV	1.000	.736	.506	.190	.144
3.4 - 4.9 MeV	.736	1.000	.894	.178	.051*
4.9 - 6.6 MeV	.506	.894	1.000	.384	.192
6.6 - 9.7 MeV	.190	.178	.384	1.000	.919
9.7 - 16 MeV	.144	.051*	.192	.919	1.000

*Significance level .06; all other significance levels are .001

about double or triple normal values. Nevertheless, both channels, with a few exceptions, track with 1.2 to 1.8 MeV variations. The four most distinct events where all three channels showed significant fluctuation occurred on June 15, 1980, April 25, 1981, July 28, 1981, and April 5, 1982.

The two highest energy channels show the most stable behavior of all the electron channels. The 6.6 to 9.7 MeV channel shows some slight variability at times. However, in all, there are only two occasions where count rates even double normal values. With one or two exceptions, rates stay very stable for the last half of the examination period.

The 9.7 to 16 MeV channel shows very similar behavior to the 6.6 to 9.7 MeV channel. Fluctuations in the 9.7 to 16 MeV channel, however slight, seem to consistently follow 6.6 to 9.7 MeV fluctuations. With one exception, values in the last 500 days of study remained very stable. The only significant change in flux occurs around October 12, 1981 (Day 853). This event was about triple normal values and corresponds exactly to the strongest event in the 6.6 to 9.7 MeV channel. This event also showed up in the 4.9 to 6.6 MeV channel.

To statistically analyze these observations, correlation coefficients were produced for all electron channels. Table I lists the results. Significance levels (P) were all .001 except where indicated. It turns out that the three

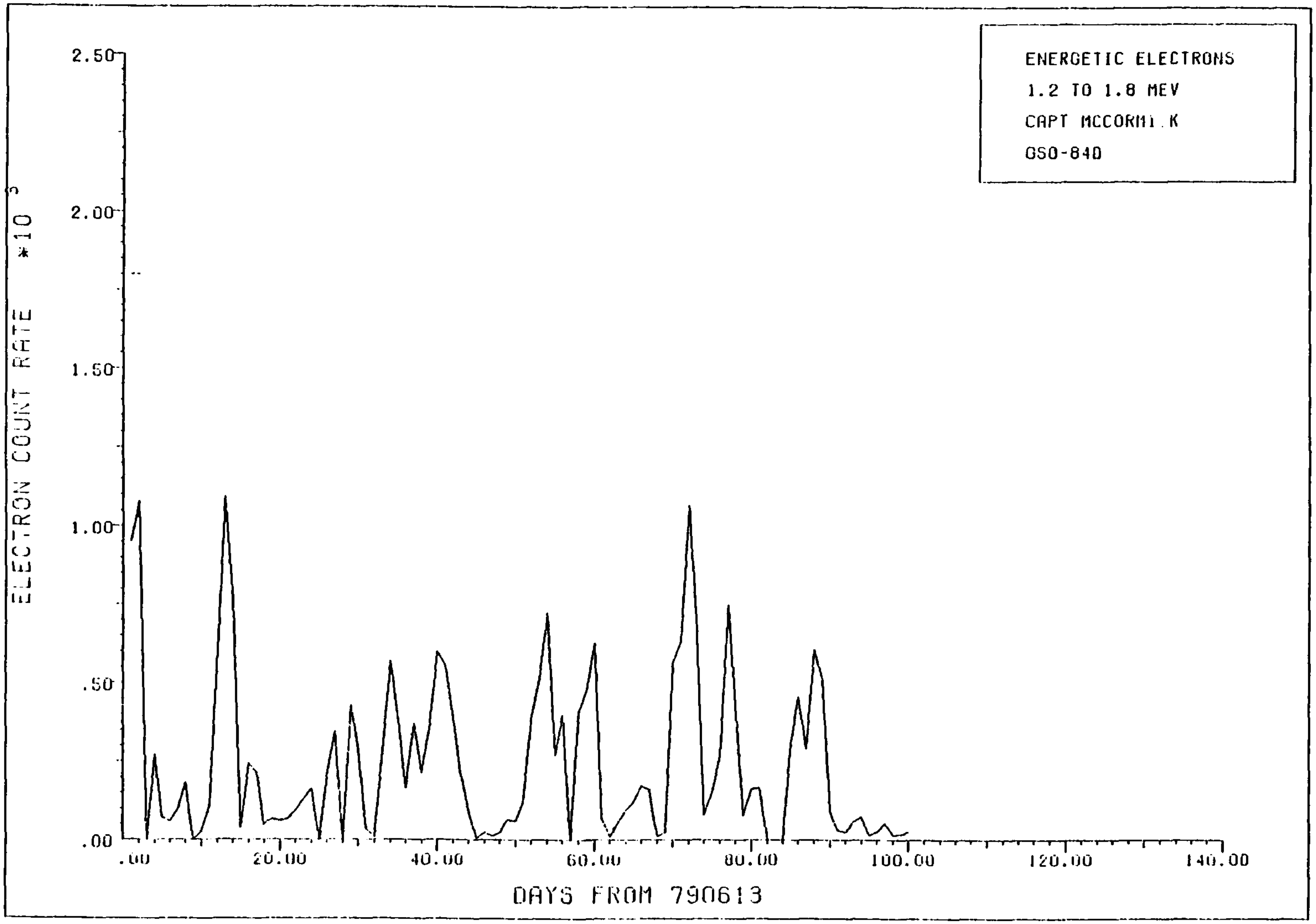


Figure 1. 1.2-1.8 MeV Electron Flux (6/13/79 - 9/20/79)

TABLE IV--Continued

Electron Data One Standard Deviation Above Mean Value

	R	R^2	Significance
6.6-9.7 MeV electron flux			
with current solar wind speed	0.349 (-0.199)	0.121 (0.040)	.001
with 1 day old solar wind speed	0.239 (-0.150)	0.057 (0.022)	.016
with 2 day old solar wind speed	0.152 (-0.137)	0.023 (0.019)	.087*
with 3 day old solar wind speed	0.092 (-0.133)	0.008 (0.018)	.198*
9.7-16 MeV electron flux			
with current solar wind speed	0.125 (-0.319)	0.015 (0.102)	.068*
with 1 day old solar wind speed	0.311 (-0.256)	0.096 (0.066)	.001
with 2 day old solar wind speed	0.387 (-0.228)	0.150 (0.052)	.001
with 3 day old solar wind speed	0.191 (-0.195)	0.036 (0.038)	.011

*Denotes values having no statistical significance

Original values are provided in parenthesis for comparison

TABLE V

CORRELATION ANALYSIS RESULTS

IMF $B_z < 0$	R	R^2	Significance
1.2-1.8 MeV electron flux			
with current solar wind speed	0.286 (0.217)	0.082 (0.047)	.001
with 1 day old solar wind speed	0.530 (0.427)	0.281 (0.182)	.001
with 2 day old solar wind speed	0.580 (0.508)	0.337 (0.258)	.001
with 3 day old solar wind speed	0.485 (0.437)	0.235 (0.191)	.001
3.4-4.9 MeV electron flux			
with current solar wind speed	0.358 (0.238)	0.128 (0.057)	.001
with 1 day old solar wind speed	0.575 (0.366)	0.331 (0.134)	.001
with 2 day old solar wind speed	0.582 (0.414)	0.339 (0.171)	.001
with 3 day old solar wind speed	0.496 (0.357)	0.246 (0.127)	.001
4.9-6.6 MeV electron flux			
with current solar wind speed	0.331 (0.197)	0.110 (0.039)	.001
with 1 day old solar wind speed	0.527 (0.280)	0.277 (0.078)	.001
with 2 day old solar wind speed	0.482 (0.288)	0.232 (0.083)	.001
with 3 day old solar wind speed	0.387 (0.226)	0.150 (0.051)	.001

TABLE V--Continued

IMF $B_z < 0$	R	R^2	Significance
6.6-9.7 MeV electron flux			
with current solar wind speed	-0.253 (-0.199)	0.064 (0.040)	.001
with 1 day old solar wind speed	-0.099 (-0.150)	0.010 (0.022)	.046
with 2 day old solar wind speed	-0.104 (-0.137)	0.011 (0.019)	.047
with 3 day old solar wind speed	-0.146 (-0.133)	0.021 (0.018)	.014
9.7-16 MeV electron flux			
with current solar wind speed	-0.374 (-0.319)	0.140 (0.102)	.001
with 1 day old solar wind speed	-0.247 (-0.256)	0.061 (0.066)	.001
with 2 day old solar wind speed	-0.244 (-0.228)	0.059 (0.052)	.001
with 3 day old solar wind speed	-0.257 (-0.195)	0.066 (0.038)	.001

Original values are provided in parenthesis for comparison

improvement. The highest R^2 value in this channel increased to 0.337 ($P = .001$) from 0.258 for two-day old solar wind. There was slight improvement in the 3.4 to 4.9 MeV channel where the highest value for R^2 increased to 0.339 ($P = .001$) from 0.171. The most noticeable improvement came in the 4.9 to 6.6 MeV channel. R^2 with one-day old solar wind jumped to 0.277 ($P = .001$) from 0.078. The best value originally had been 0.091 for one and a half day old solar wind values. The 6.6 to 9.7 MeV and 9.7 to 16 MeV channels showed, essentially, no effect from negative B_z. R and R^2 values in both channels showed virtually no change from original correlation results.

To further check the effects of solar wind fluctuations to electron flux, another set of correlation calculations were made. This time solar wind velocities were squared for comparison with electron flux (see Table VI). The motivation for this approach came from a journal article by Akasofu (Akasofu, 1983:173-183). As described earlier, Akasofu provides an equation for the total energy output rate of the magnetosphere that is linear with solar wind speed. However, also provided is a list of correlation studies between geomagnetic indices and solar wind parameters. Some of these studies use squared solar wind speed in relation equations (Akasofu, 1983:174). The R and R^2 values obtained with this approach were virtually identical to original results involving correlation with solar wind velocity.

TABLE VI

CORRELATION ANALYSIS RESULTS

Electron Flux With Solar Wind Squared	R	R^2	Significance
<u>1.2-1.8 MeV electron flux</u>			
with current (solar wind speed)^2	0.218 (0.217)	0.047 (0.047)	.001
with 1 day old (solar wind speed)^2	0.431 (0.427)	0.186 (0.182)	.001
with 2 day old (solar wind speed)^2	0.512 (0.508)	0.262 (0.258)	.001
with 3 day old (solar wind speed)^2	0.435 (0.437)	0.189 (0.191)	.001
<u>3.4-4.9 MeV electron flux</u>			
with current (solar wind speed)^2	0.256 (0.238)	0.066 (0.057)	.001
with 1 day old (solar wind speed)^2	0.393 (0.366)	0.154 (0.134)	.001
with 2 day old (solar wind speed)^2	0.438 (0.414)	0.192 (0.171)	.001
with 3 day old (solar wind speed)^2	0.369 (0.357)	0.136 (0.127)	.001
<u>4.9-6.6 MeV electron flux</u>			
with current (solar wind speed)^2	0.226 (0.197)	0.051 (0.039)	.001
with 1 day old (solar wind speed)^2	0.315 (0.280)	0.099 (0.078)	.001
with 2 day old (solar wind speed)^2	0.317 (0.288)	0.100 (0.083)	.001
with 3 day old (solar wind speed)^2	0.237 (0.226)	0.056 (0.051)	.001

TABLE VI--Continued

Electron Flux With Solar Wind Squared	R	R^2	Significance
6.6-9.7 MeV electron flux			
with current (solar wind speed)^2	-0.187 (-0.199)	0.035 (0.040)	.001
with 1 day old (solar wind speed)^2	-0.136 (-0.150)	0.019 (0.022)	.001
with 2 day old (solar wind speed)^2	-0.122 (-0.137)	0.015 (0.019)	.001
with 3 day old (solar wind speed)^2	-0.125 (-0.133)	0.016 (0.018)	.001
9.7-16 MeV electron flux			
with current (solar wind speed)^2	-0.308 (-0.319)	0.095 (0.102)	.001
with 1 day old (solar wind speed)^2	-0.247 (-0.256)	0.061 (0.066)	.001
with 2 day old (solar wind speed)^2	-0.218 (-0.228)	0.047 (0.052)	.001
with 3 day old (solar wind speed)^2	-0.190 (-0.195)	0.036 (0.038)	.001

Original values are provided in parenthesis for comparison

Final correlation analysis results using solar wind and the IMF B_z component were varied. Different combinations of solar wind and B_z conditions were employed to see if correlation results improved. The first combination correlated staggered solar wind with the 1.2 to 1.8 MeV electron channel for those cases where the solar wind was above one standard deviation above the mean and IMF B_z was negative (see Table VII). The strongest statistically significant results for this combination were even weaker than original results. Two-day old solar wind had an R^2 of 0.251 ($P = .001$) compared to 0.258 previously. A second combination correlated two-day old squared solar wind with the three lowest energy channels for cases where two-day old B_z was negative (see Table VIII). All of these values were statistically significant. All R^2 values using this combination were slightly stronger than original results. However, stronger correlations were seen with negative B_z (see Table V). R^2 values in the 3.4 to 4.9 MeV channel may be used as an example. R^2 for two-day old solar wind was originally 0.171, but jumped to 0.339 with negative B_z. R^2 increased to just 0.269 ($P = .001$) with two-day old solar wind squared and two-day old B_z negative. The 1.2 to 1.8 MeV and 4.9 to 6.6 MeV channels showed similar results.

The last correlation analysis accomplished in this study took a different approach. Here, electron count rates were correlated against the IMF average magnitude (B magnitude). The motivation for this attempt is the possibility that the

TABLE VII

CORRELATION ANALYSIS RESULTS

Solar Wind > 490 km/sec and IMF $B_z < 0$			
	R	R^2	Significance
1.2-1.8 MeV electron flux			
with current solar wind speed	0.156 (0.217)	0.024 (0.047)	0.159*
with 1 day old solar wind speed	0.297 (0.427)	0.088 (0.182)	0.035
with 2 day old solar wind speed	0.501 (0.508)	0.251 (0.258)	0.001

*Denotes values having no statistical significance

Original values are provided in parenthesis for comparison

TABLE VIII

CORRELATION ANALYSIS RESULTS

Two Day Old IMF $B_z < 0$			
	R	R^2	Significance
1.2-1.8 MeV electron flux			
with 2 day old (solar wind speed)^2	0.559 (0.508)	0.313 (0.258)	.001
3.4-4.9 MeV electron flux			
with 2 day old (solar wind speed)^2	0.518 (0.414)	0.269 (0.171)	.001
4.9-6.6 MeV electron flux			
with 2 day old (solar wind speed)^2	0.392 (0.288)	0.154 (0.083)	.001

*Denotes values having no statistical significance

Original values are provided in parenthesis for comparison

IMF magnitude may somehow modulate the number of galactic cosmic ray electrons that penetrate into the magnetosphere on a day-to-day basis. In particular, an increased B magnitude may decrease the number of energetic particles. Perhaps electrons above 6.6 MeV are affected by this process. The theory behind this approach is not well founded. However, evidence exists to support this idea for higher energy electrons on longer time intervals (Fulks, 1975:1701). The results obtained did indeed show a negative correlation which is slightly stronger for the two channels above 6.6 MeV than the two just below 6.6 MeV. Nevertheless, R^2 values were again weak. Results are shown in Table IX.

ANOVA

ANOVA was used in this study to further investigate the relationship between electron fluxes and solar wind and IMF variations. Electron fluxes from each respective energy channel were used as the dependent variables. Current and staggered solar wind speed and the IMF B_z component were used as independent variables. Solar wind levels were based on standard deviation units away from the solar wind mean. IMF B_z levels were based on positive and negative values only.

Solar wind was initially factored into five levels. Level one consisted of all solar wind values more than one standard deviation below the mean. Level two was composed of values between the mean and one standard deviation below the mean. Level three was made up of values between the mean and

TABLE IX

CORRELATION ANALYSIS RESULTS

IMF Average Magnitude			
	R	R^2	Significance
1.2-1.8 MeV electron flux with B magnitude	-0.317	0.101	.000
3.4-4.9 MeV electron flux with B magnitude	-0.165	0.027	.000
4.9-6.6 MeV electron flux with B magnitude	-0.140	0.020	.000
6.6-9.7 MeV electron flux with B magnitude	-0.281	0.079	.000
9.7-16 MeV electron flux with B magnitude	-0.282	0.080	.000

one standard deviation above the mean. Level four was composed of solar wind values between one and two standard deviations above the mean, and level five consisted of all values above two standard deviations above the mean. IMF B_z was separated into two levels for positive and negative values. This initial selection of levels was for two reasons. The first was to distinguish solar wind enhancement effects and the effects of positive and negative B_z values. The second was to confirm results from earlier work by Smith (Smith, 1983).

Results from these tests did not indicate any relationship at work stronger than linear. In particular, none of the tests with solar wind yielded R^2 results greater than 0.15. For example, R^2 for 1.2-1.8 MeV electron flux and two-day old solar wind was 0.141 with a significance of .001. The highest statistically significant R^2 values from the four highest electron channels with solar wind were all below 0.10. These results are summarized in Table X.

Two-way ANOVA was used to investigate the relationship between energetic electron fluxes and solar wind and IMF B_z. Here, solar wind and B_z were used as the independent variables and respective electron fluxes as the dependent variable. The purpose was to evaluate the joint effects of solar wind and B_z on electron fluxes. Two-way ANOVA results did not indicate any strong effect to electron fluxes in any energy channel but generally did increase R^2 values above the previous ANOVA study. The highest R^2 value occurred with the 1.2 to 1.8 MeV channel with two-day old solar wind. These results are presented in Table XI.

TABLE X

ANOVA RESULTS - 5 FACTOR LEVELS

Dependent Variable	Independent Variable	R^2	Significance
1.2-1.8 MeV electron flux	Solar Wind Speed (two day old)	0.141*	.001
3.4-4.9 MeV electron flux	Solar Wind Speed (two day old)	0.089*	.001
4.9-6.6 MeV electron flux	Solar Wind Speed (two day old)	0.039*	.001
6.6-9.7 MeV electron flux	Solar Wind Speed (same day value)	0.013*	.001
9.7-16 MeV electron flux	Solar Wind Speed (same day value)	0.036*	.001

*Denotes values confirmed in earlier study by Smith (1983)

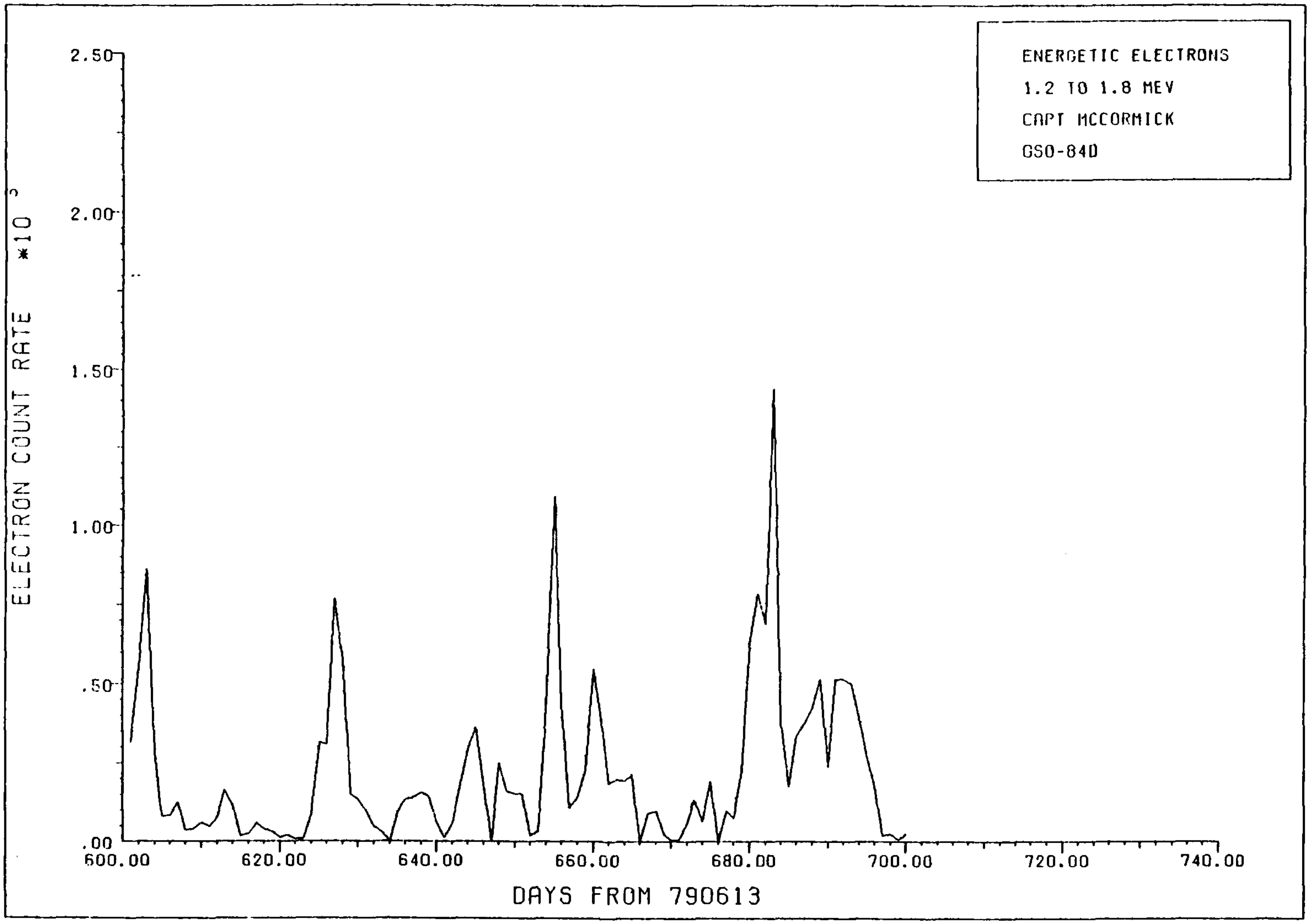
TABLE XI

TWO-WAY ANOVA RESULTS

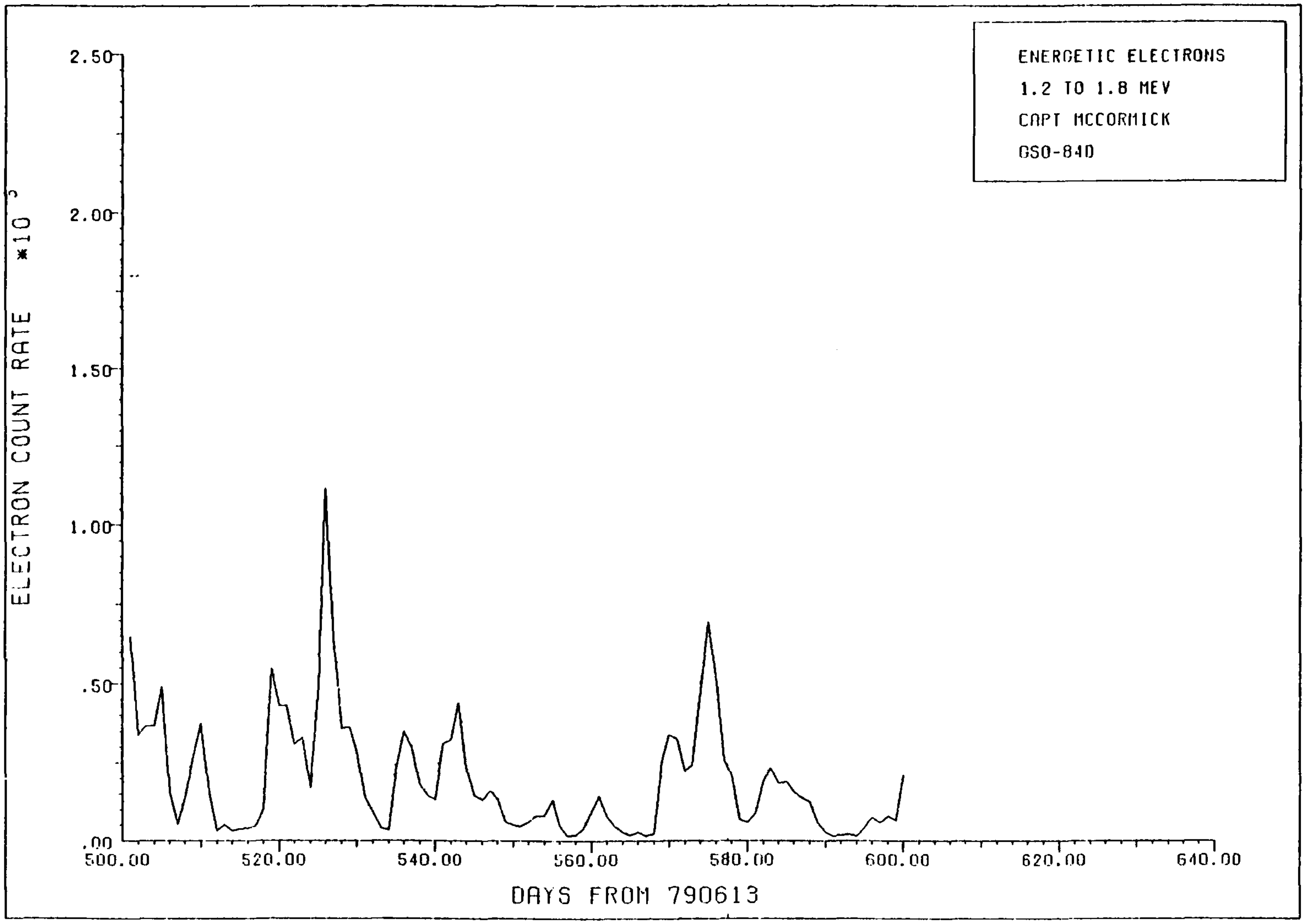
Dependent Variable	Independent Variable **	R^2	Significance
1.2-1.8 MeV electron flux	Solar Wind Speed (two day old) IMF B_z component	0.177*	.001
3.4-4.9 MeV electron flux	Solar Wind Speed (two day old) IMF B_z component	0.113*	.001
4.9-6.6 MeV electron flux	Solar Wind Speed (two day old) IMF B_z component	0.057*	.001
6.6-9.7 MeV electron flux	Solar Wind Speed IMF B_z component	0.071*	.001
9.7-16 MeV electron flux	Solar Wind Speed IMF B_z component	0.117*	.001

*Denotes values confirmed in earlier study by Smith (1983)

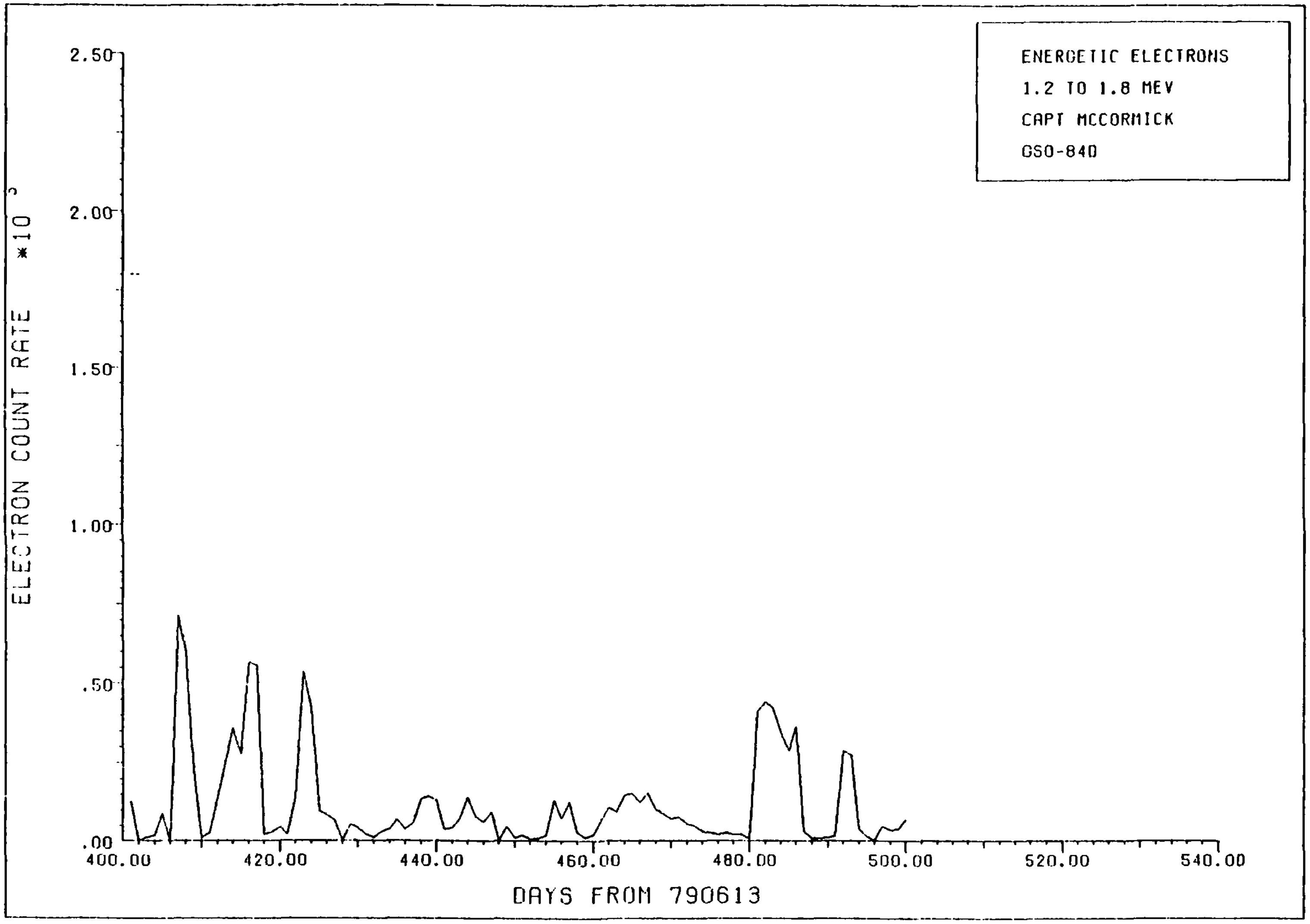
**All values of solar wind and IMF are same day values as the electron fluxes except as explicitly noted.



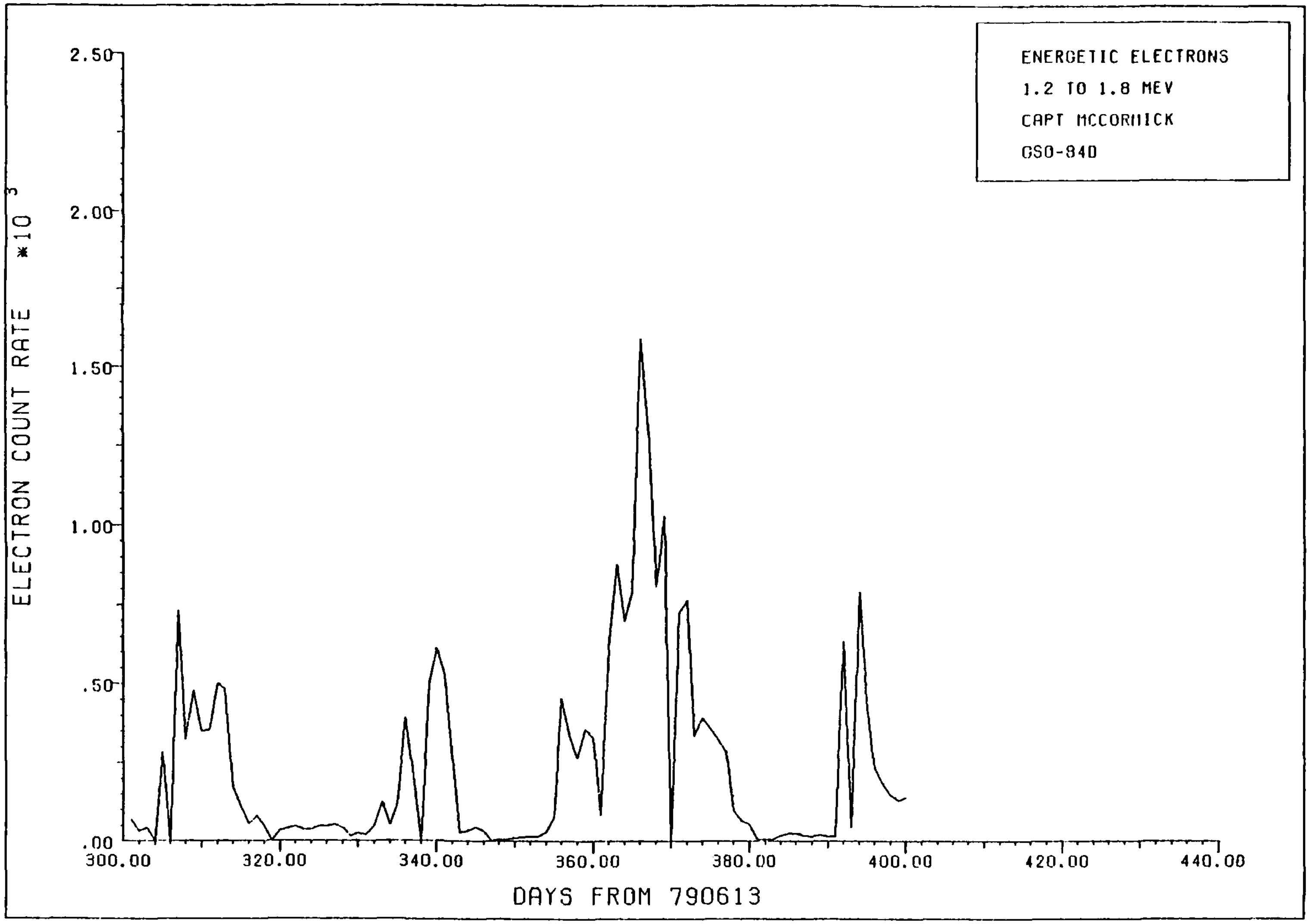
1.2 - 1.8 MeV Electron Flux (2/2/81 - 5/12/81)



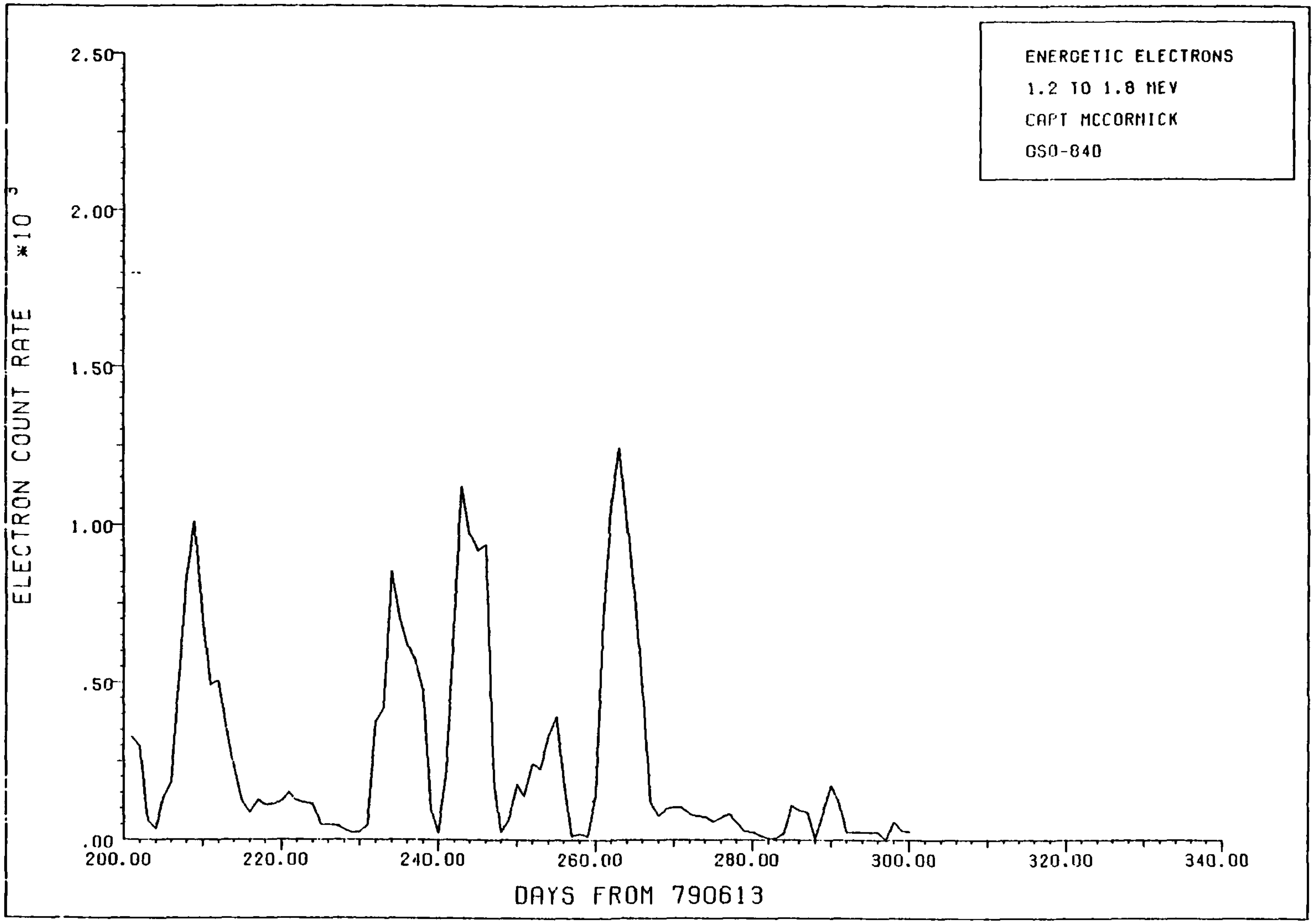
1.2 - 1.8 MeV Electron Flux (10/25/80 - 2/1/81)



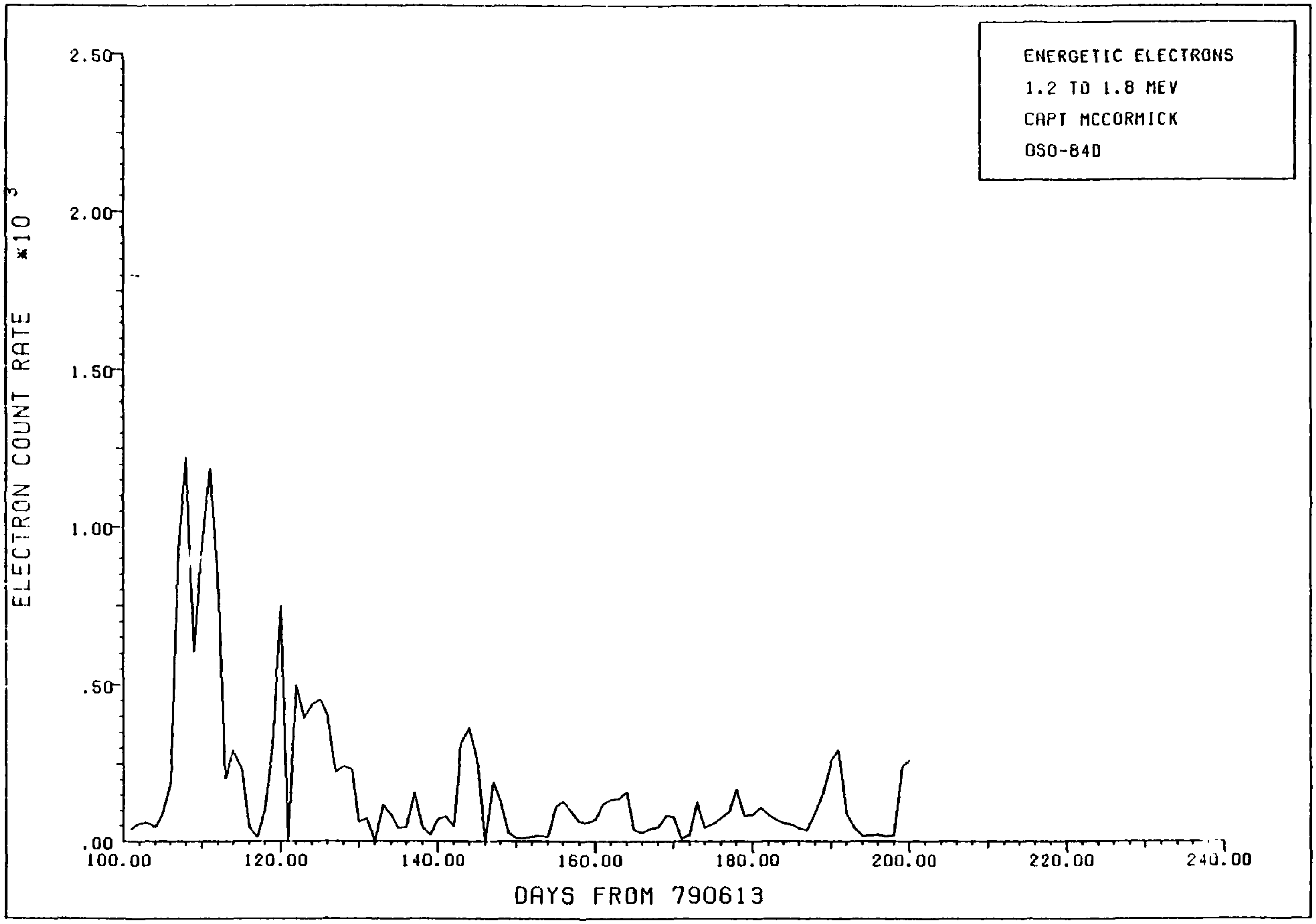
1.2 - 1.8 MeV Electron Flux (7/17/80 - 10/24/80)



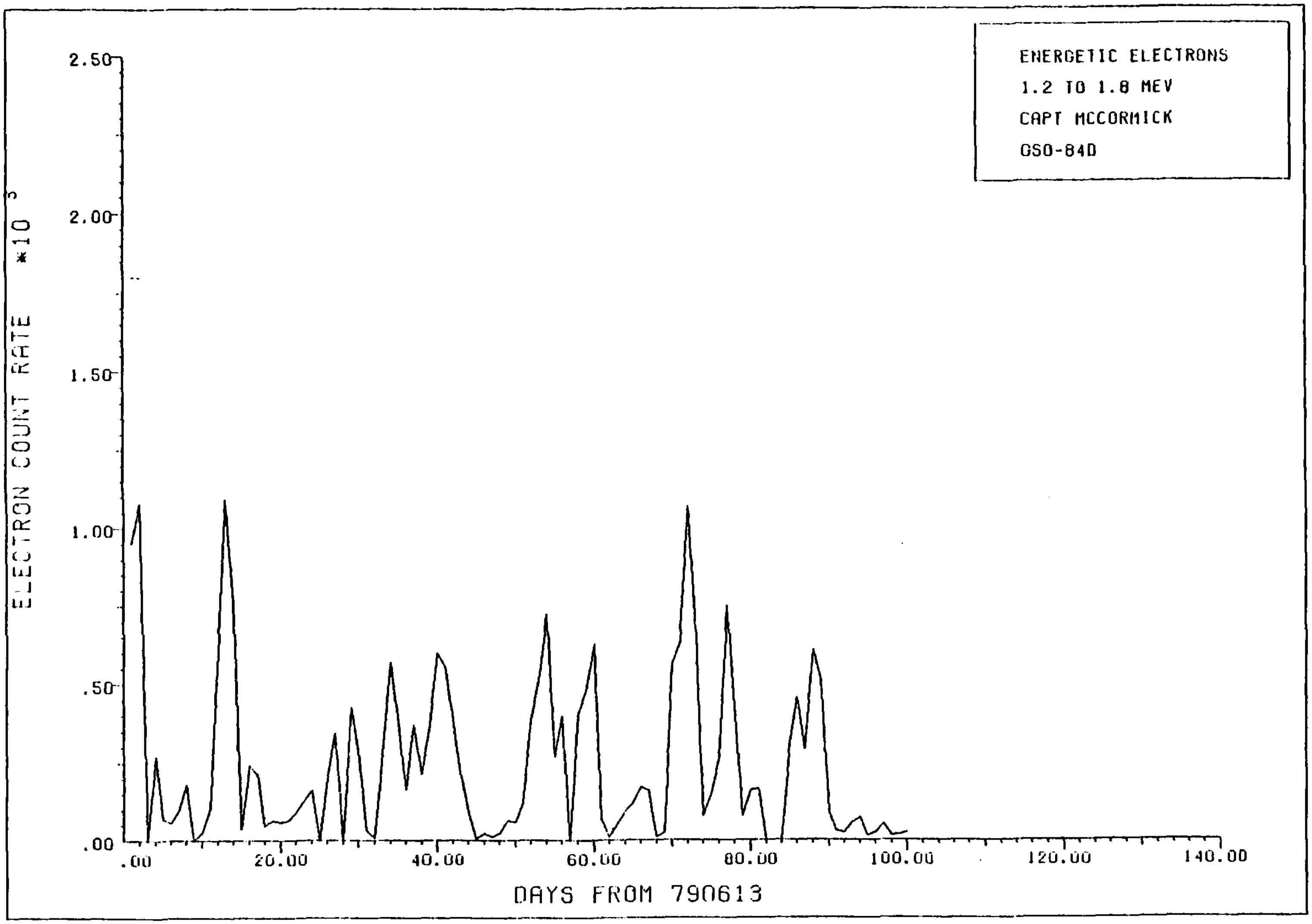
1.2 - 1.8 MeV Electron Flux (4/8/80 - 7/16/80)



1.2 - 1.8 MeV Electron Flux (12/30/79 - 4/7/80)



1.2 - 1.8 MeV Electron Flux (9/21/79 - 12/29/79)



1.2 - 1.8 MeV Electron Flux (6/13/79 - 9/20/79)

Appendix: Graphical Plots

Graphical plots of electron count rates, solar wind speed, and the IMF B_z component are presented on the following pages. A few particulars should be noted:

1. The horizontal axis in all plots represents a chronological index of days in the study period, i.e., day 1 is June 13, 1979, day 100 is September 20, 1979, etc.

2. Ten plots are presented for each parameter with one hundred days to a plot.

3. Missing values are coded as zero. This causes some distortion of the data, particularly in solar wind speed plots.

wind values were missing. A second recommendation would be to conduct further analysis on significant electron flux enhancements, specifically those days where electron flux exceeds one standard deviation above the mean. For example, what were specific solar wind and IMF conditions surrounding each enhancement, and how long did the enhancement last. Perhaps a more promising approach for investigation in this area is the Active Magnetospheric Particle Tracer Explorers (AMPTE) program coordinated by NASA Goddard Spaceflight Center. As of this writing, three AMPTE spacecraft are to be used to obtain new data on the Van Allen radiation belts (Covault, 1984:54). If all goes well, quite a bit of new data should be available for analysis.

processes affect electron fluctuations in the three lowest channels are different from those affecting the two highest channels.

Overall, solar wind influence appears to diminish as electron energy increases. Weak correlation results become even weaker for each higher energy channel up to 6.6 MeV. In spite of this, it is evident that for these channels, 36 to 48 hour old solar wind values show the strongest correlation with electron fluxes. This could indicate that the mechanism accelerating these electrons takes up to two days to be most effective. Solar wind effects on electrons above 6.6 MeV are not significant.

IMF results were more indecisive. No correlation whatsoever existed between IMF B_z or magnitude components. However, solar wind correlation results in the three lowest energy channels improved slightly when B_z was negative. This tended to support existing theory. IMF modulation of electrons between 6.6 and 16 MeV was nonexistent. Current speculation includes the possibility of IMF modulation of galactic cosmic rays as a source for these high energy electrons. If this is indeed the case, this study did not show it.

Recommendations

This author would recommend several things. First, if this data is used for further analysis, an attempt should be made to fill in the missing solar wind data. In the last half of the study period, as much as 30% of the hourly solar

V. Conclusions and Recommendations

Conclusions

The ultimate objective of this research was to determine if a predictive capability could be developed for energetic electron fluctuations in the magnetosphere. The solar wind and Interplanetary Magnetic Field effects were primarily investigated as possible causes for these fluctuations.

It appears that there are clear differences between the behavior of 1.2-6.6 MeV electrons and 6.6-16 MeV electrons at geosynchronous orbit. The first evidence of this was the linear correlation shown between the various energy channels. The three lowest channels showed relatively strong correlation with each other. The two highest channels also showed strong correlation with each other but not to the lower three. Further indications of different behavior showed up in correlation results with the solar wind. Although admittedly weak, the three lowest channels all showed positive correlation coefficients. In particular, these three channels also showed that one and a half to two-day old solar wind correlated best with electron fluxes. The two highest channels both showed negative correlation coefficients with solar wind values. These results would tend to support the idea that whatever defined as follows. The first group included all days where no events occurred in any of the three electron channels. The second group included those days where at least one but not all three channels showed events. Group three contained just those occasions where all three channels showed events. The two discriminating variables used were two-day old solar wind and IMF B_z values. The results of this analysis indicated that, of the two, solar wind was the only statistically significant variable in separating the three groups. Specifically, B_z significance was 0.341 compared to .000 for two-day old solar wind. Classification results are presented in Table XIII. It turns out that almost 67% of grouped cases were correctly classified.

TABLE XIII

DISCRIMINANT ANALYSIS RESULTS

Group	Number of Cases	Predicted Group Membership		
		Group 1	Group 2	Group 3
1 - No events in any channel	669	465	141	63
2 - At least one but not three events	70	24	32	14
3 - Events in all three channels	23	3	7	13

TABLE XII

ANOVA RESULTS - 3 FACTOR LEVELS

Dependent Variable	Independent Variable	R^2	Significance
1.2-1.8 MeV electron flux	Solar Wind Speed (two day old)	0.104	.001
3.4-4.9 MeV electron flux	Solar Wind Speed (two day old)	0.059	.001
4.9-6.6 MeV electron flux	Solar Wind Speed (two day old)	0.024	.001
6.6-9.7 MeV electron flux	Solar Wind Speed (two day old)	0.003	.231*
9.7-16 MeV electron flux	Solar Wind Speed (two day old)	0.009	.013

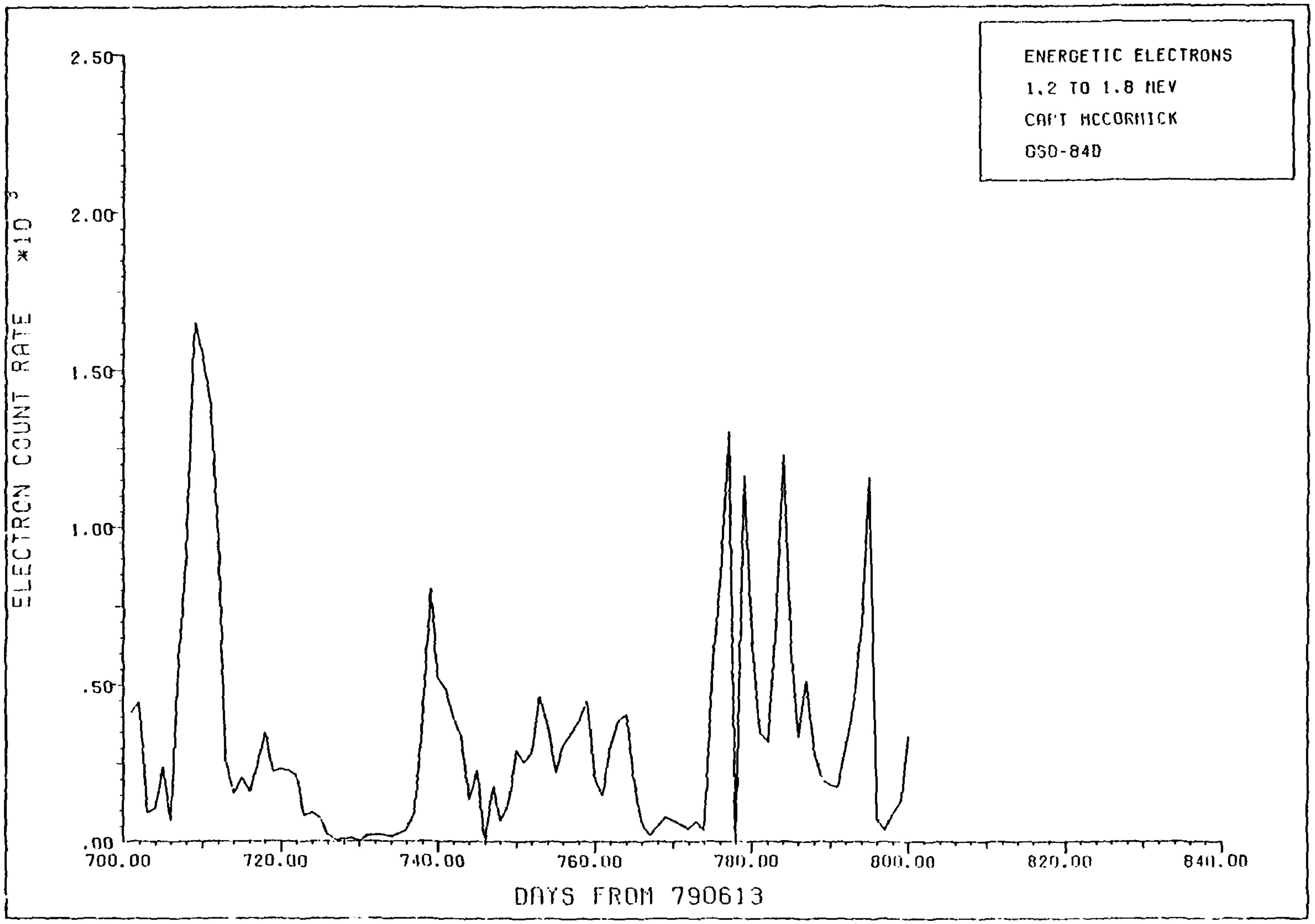
*Denotes values having no statistical significance

The final investigation using ANOVA techniques used different levels of solar wind. This time only three levels were used. In addition, all levels were for two-day old solar wind. Two-day old solar wind was used due to "positive" results obtained in correlation analysis for this time delay. Level one consisted of all solar wind values below the mean. Level two was composed of all values between the mean and 1½ standard deviations above the mean. Level three consisted of all solar wind values above 1½ standard deviations above the mean. Results for this grouping were not much different from earlier results. Once again the 1.2 to 1.8 MeV channel showed the highest R^2 value. This was a weak 0.104 (P = .001). Further results are available in Table XII.

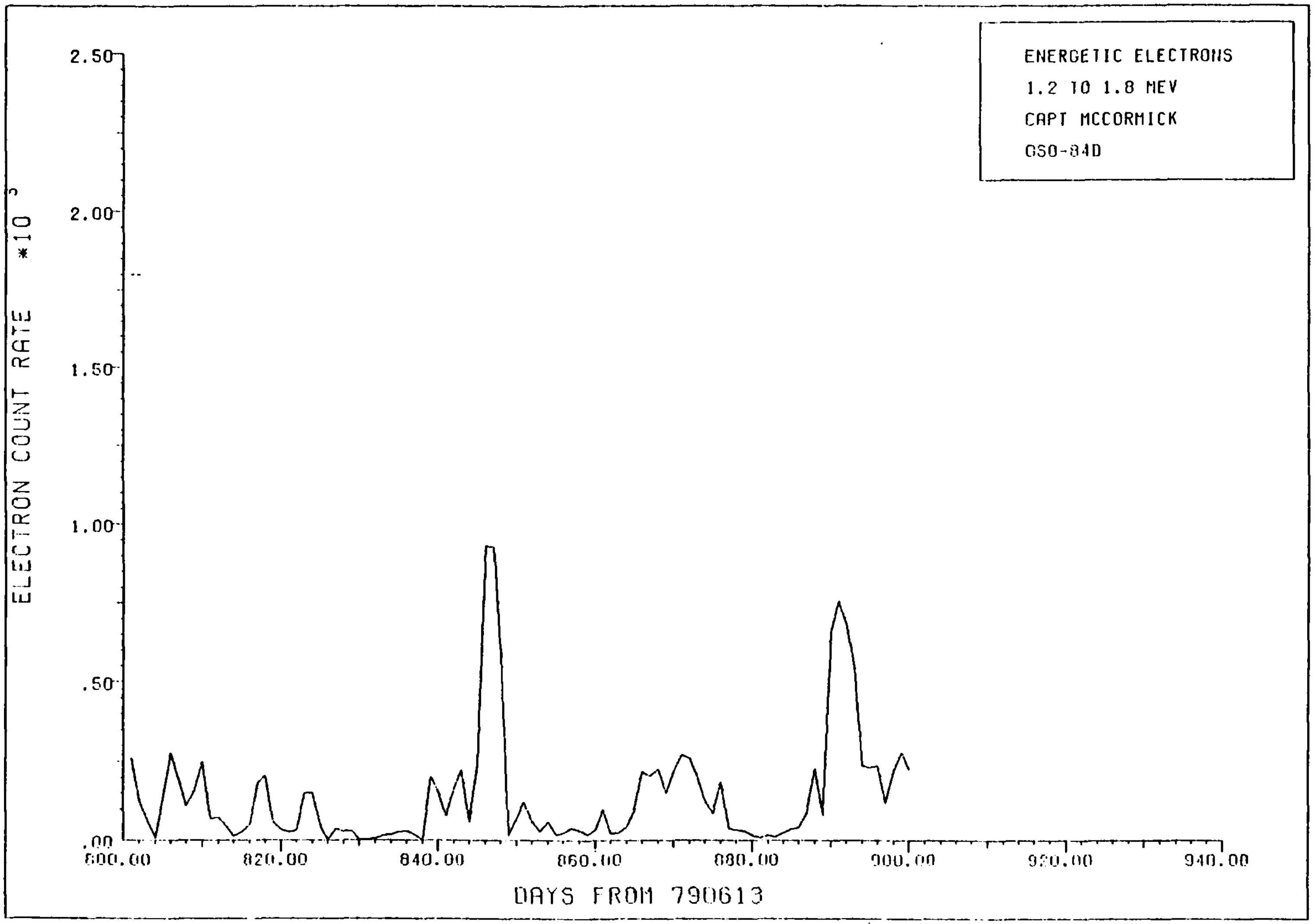
In summary, ANOVA testing did not reveal any indications of stronger relationships between electron fluxes and solar wind or the IMF B_z component than have already been evaluated.

Discriminant Analysis

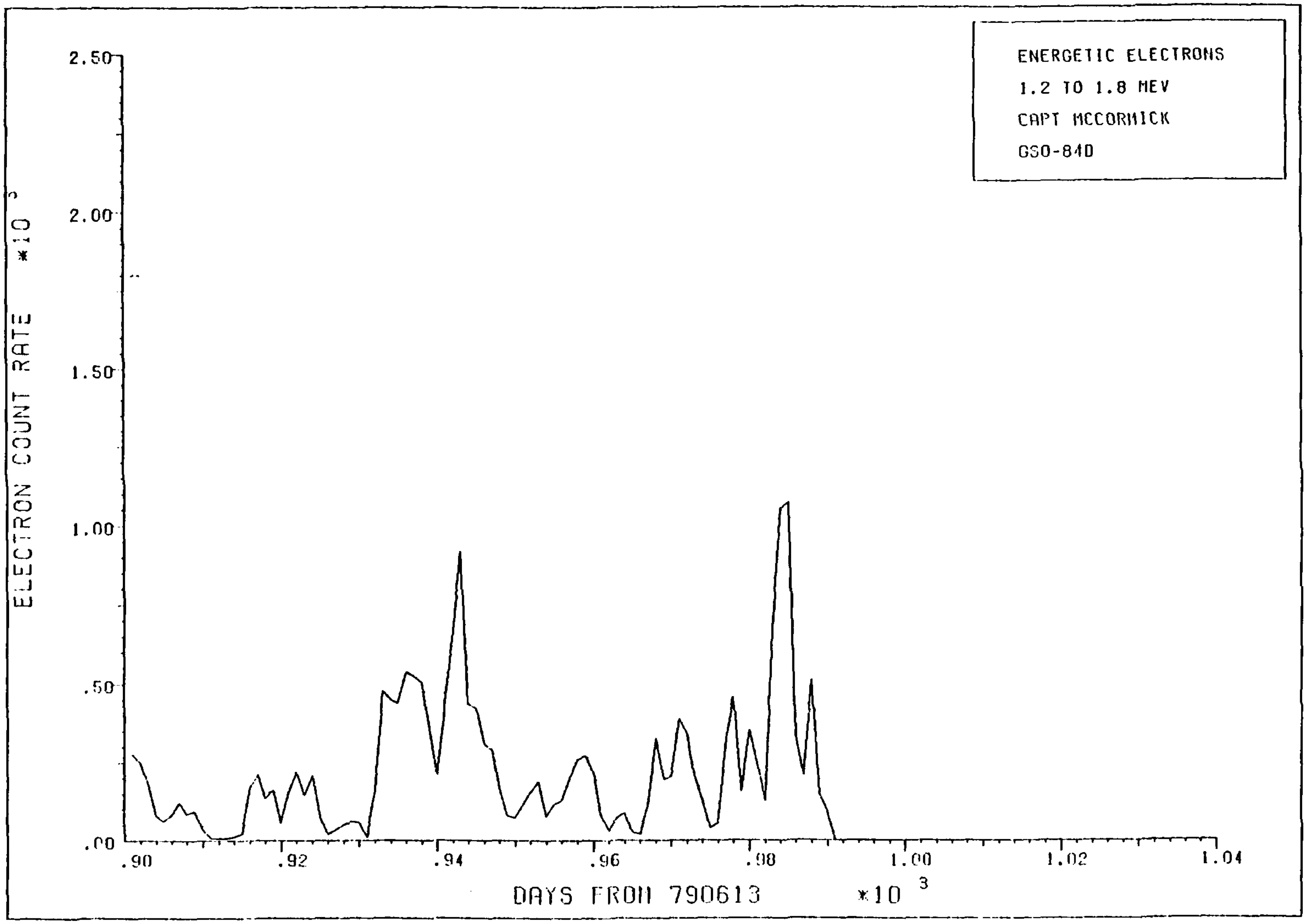
The final statistical technique used in this study involved discriminant analysis. Results to this point have indicated the possibility of similar behavior among the three lowest electron channels. To further investigate this possibility, association between "events" in each channel and two-day old solar wind and IMF B_z was attempted. First, events in each of the three energy channels were defined as values above one standard deviation above the mean. Next, three groups were



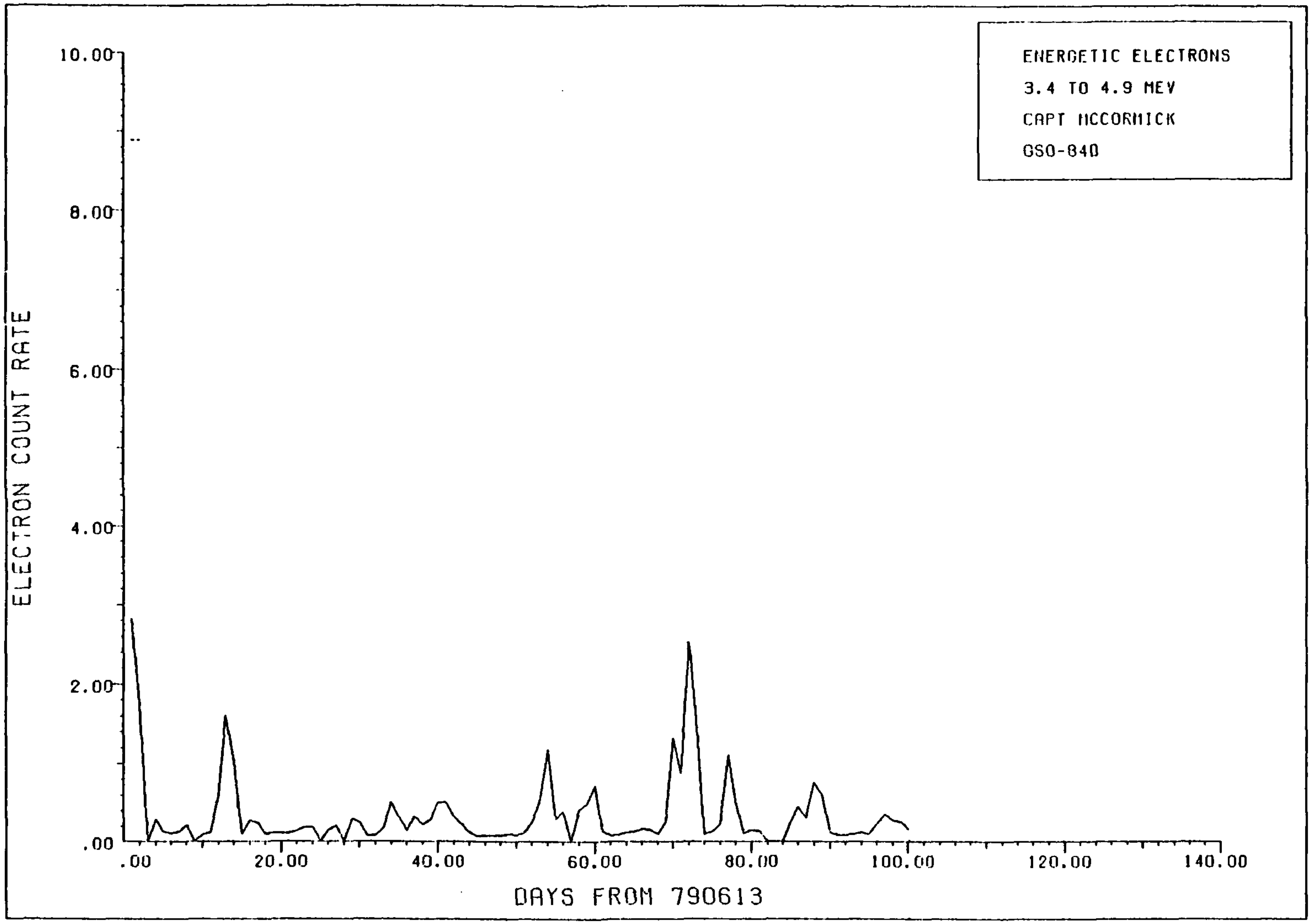
1.2 - 1.8 MeV Electron Flux (5/13/81 - 8/20/81)



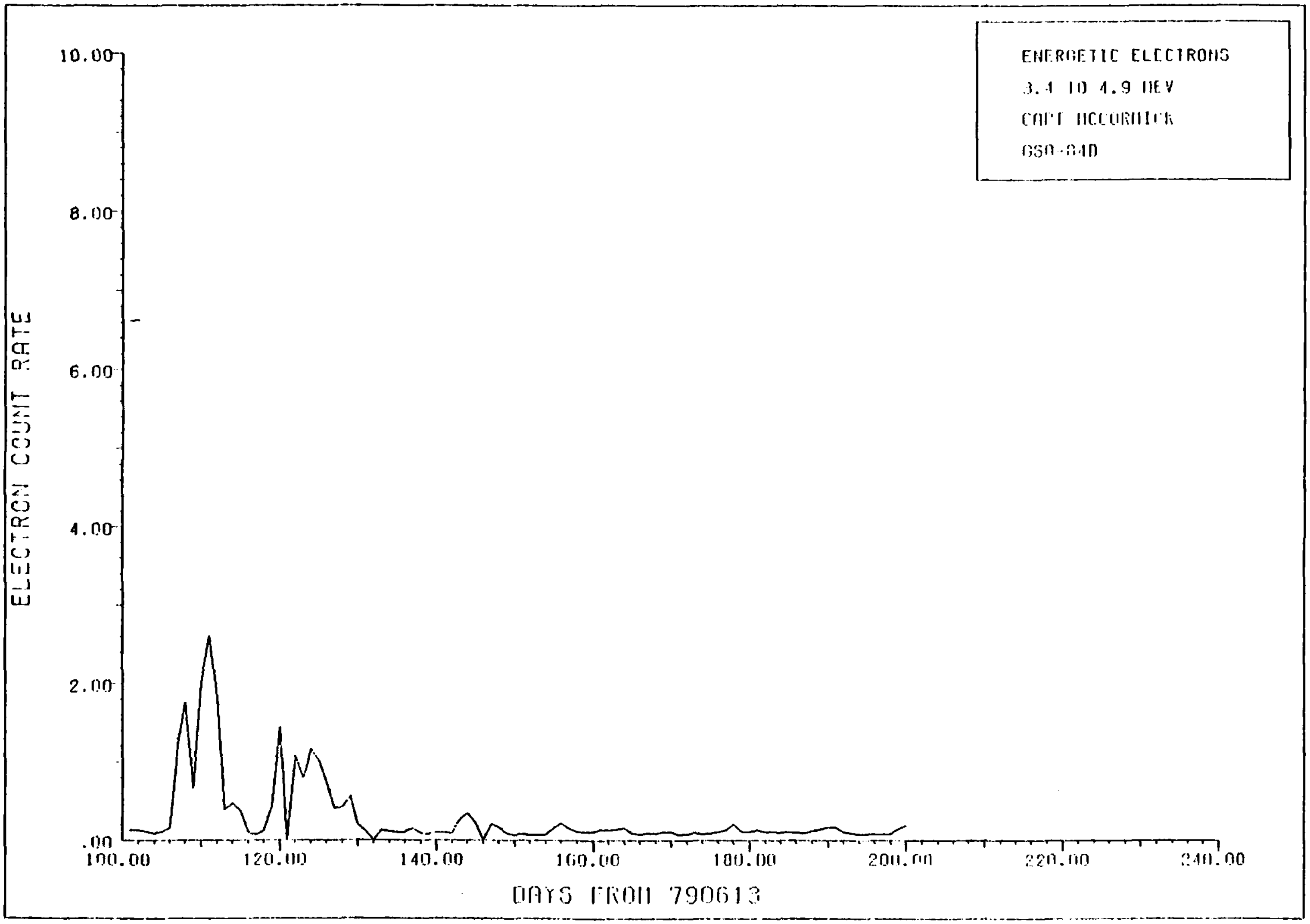
1.2 - 1.8 MeV Electron Flux (8/21/81 - 11/28/81)



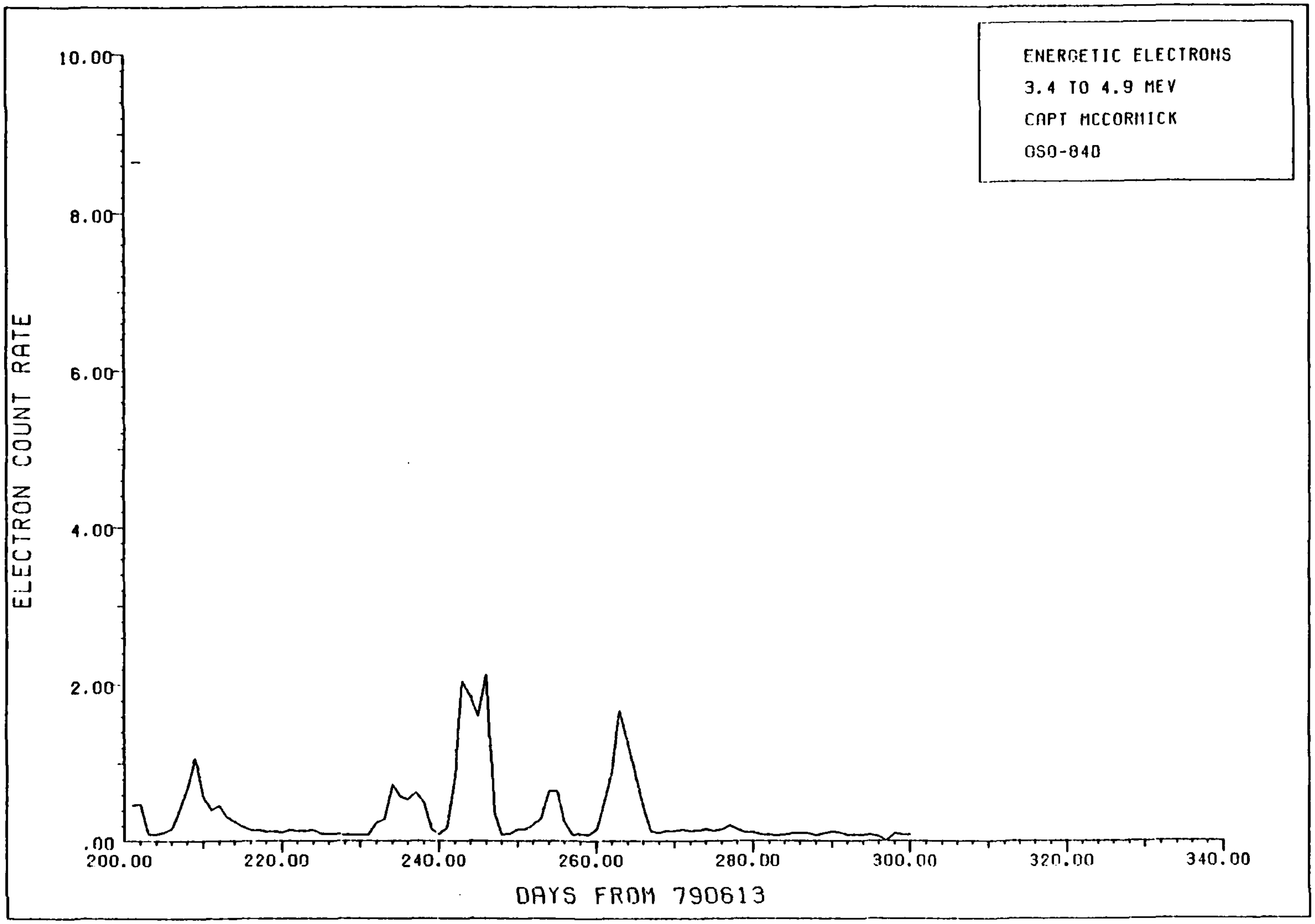
1.2 - 1.8 MeV Electron Flux (11/29/81 - 3/8/82)



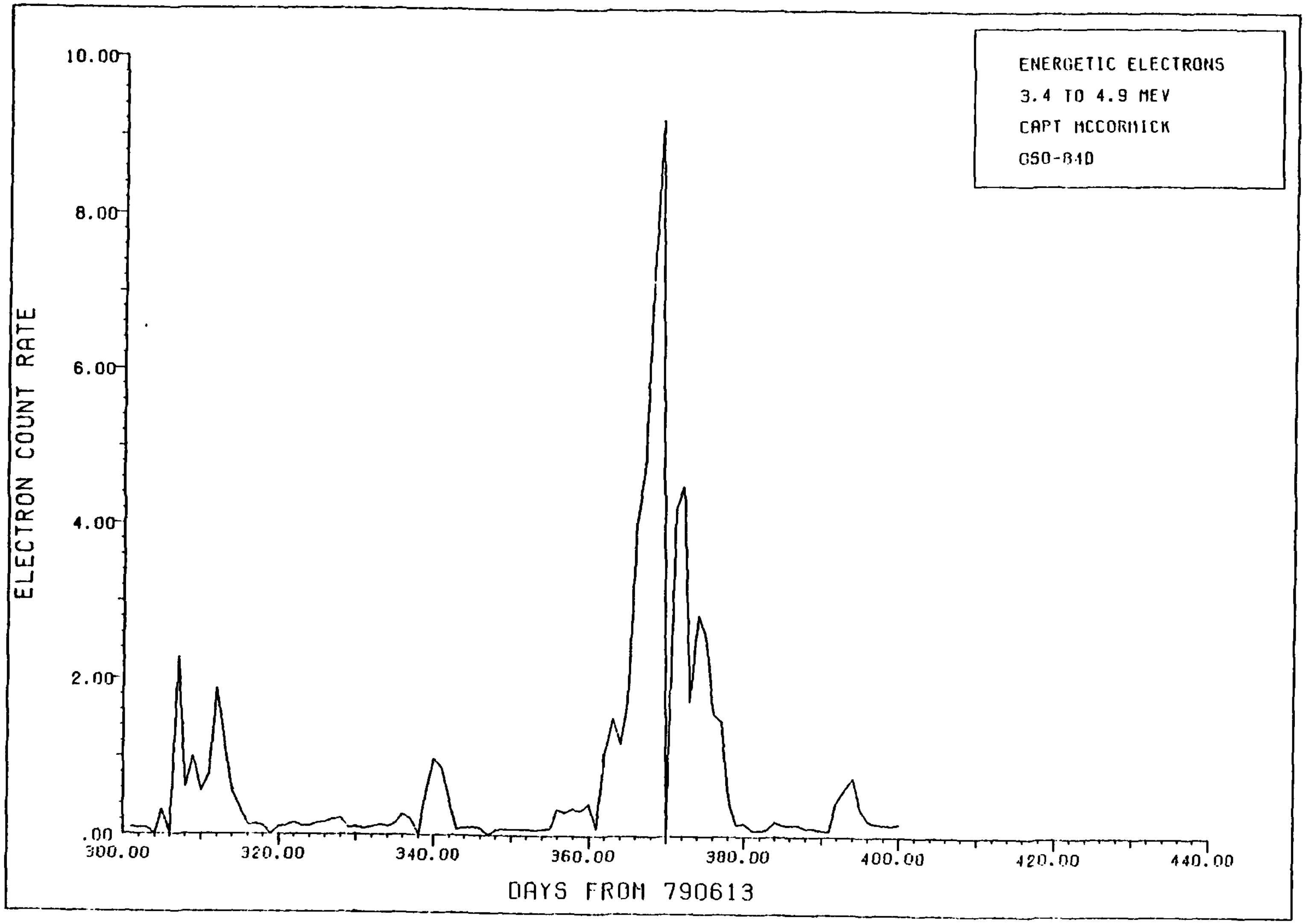
3.4 - 4.9 MeV Electron Flux (6/13/79 - 9/20/79)



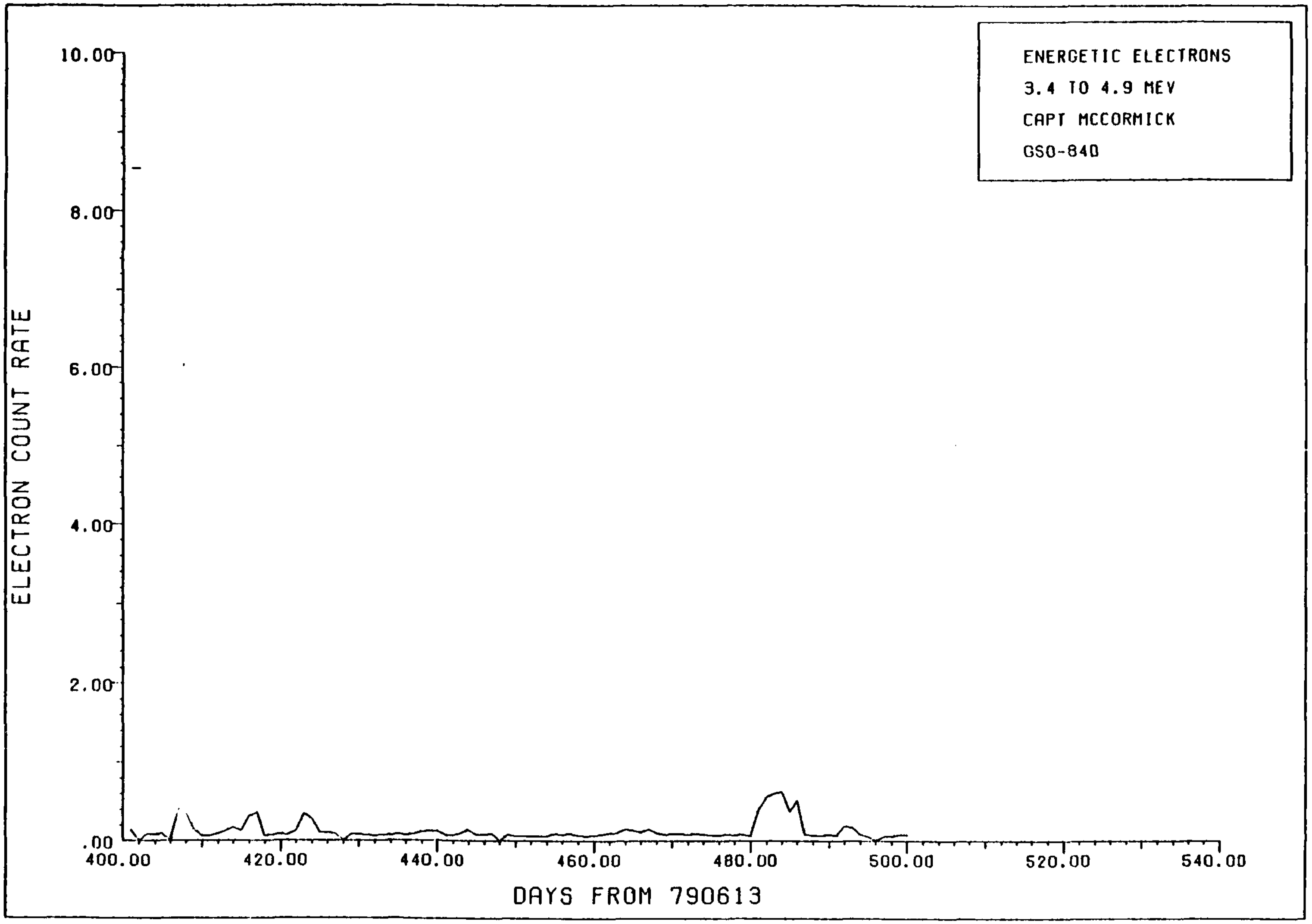
3.4 - 4.9 MeV Electron Flux (9/21/79 - 12/29/79)



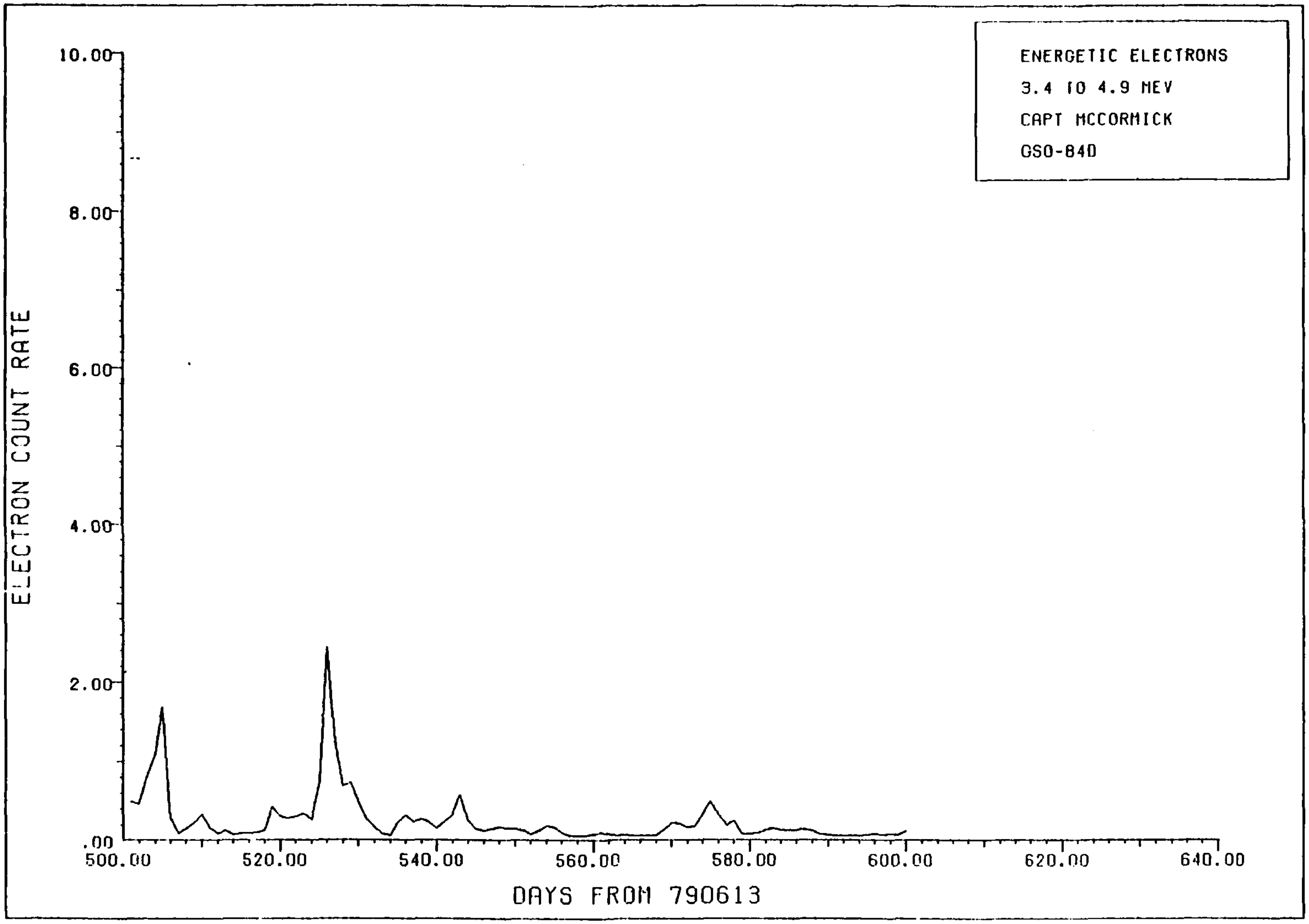
3.4 - 4.9 MeV Electron Flux (12/30/79 - 4/7/80)



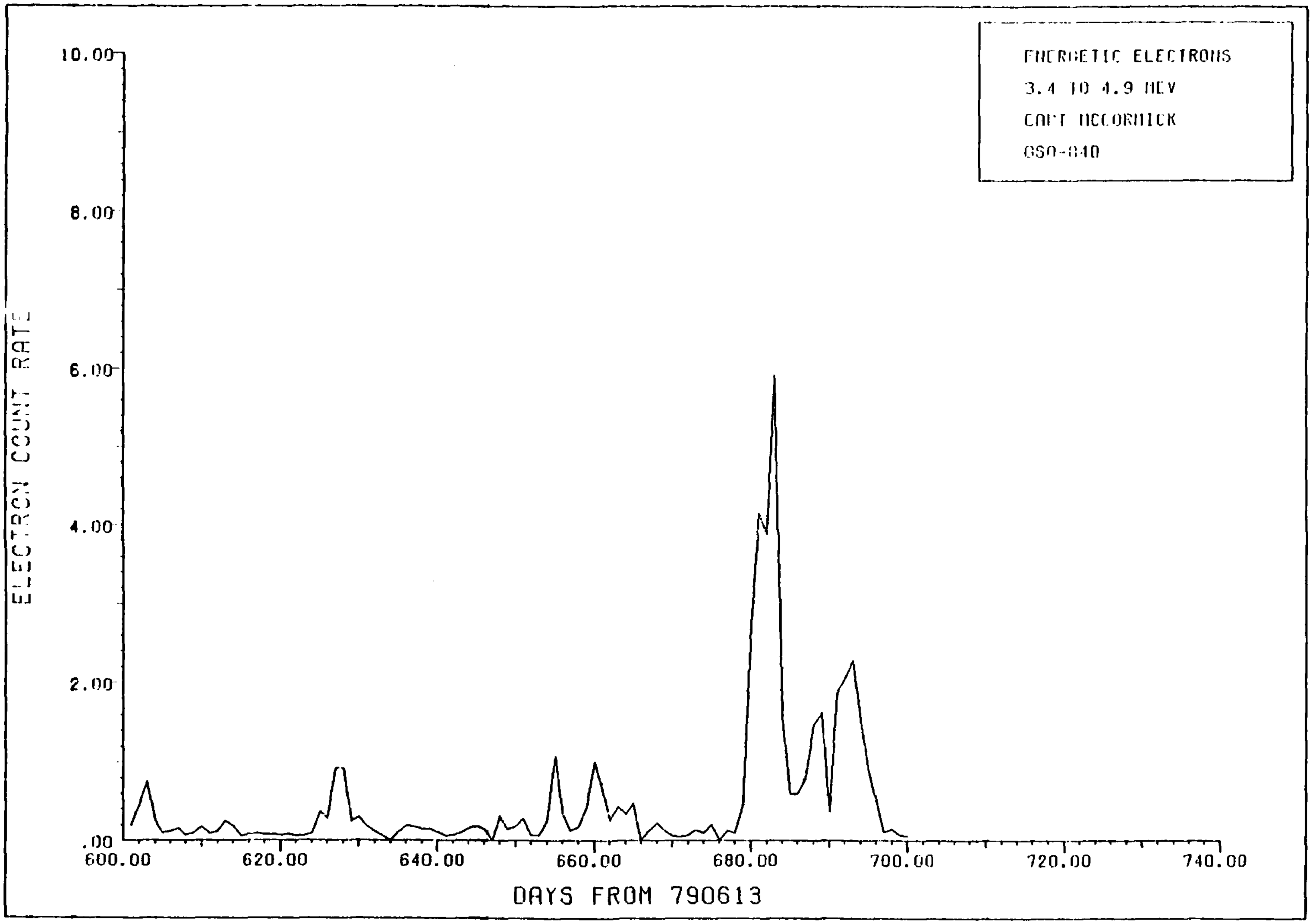
3.4 - 4.9 MeV Electron Flux (4/8/80 - 7/16/80)



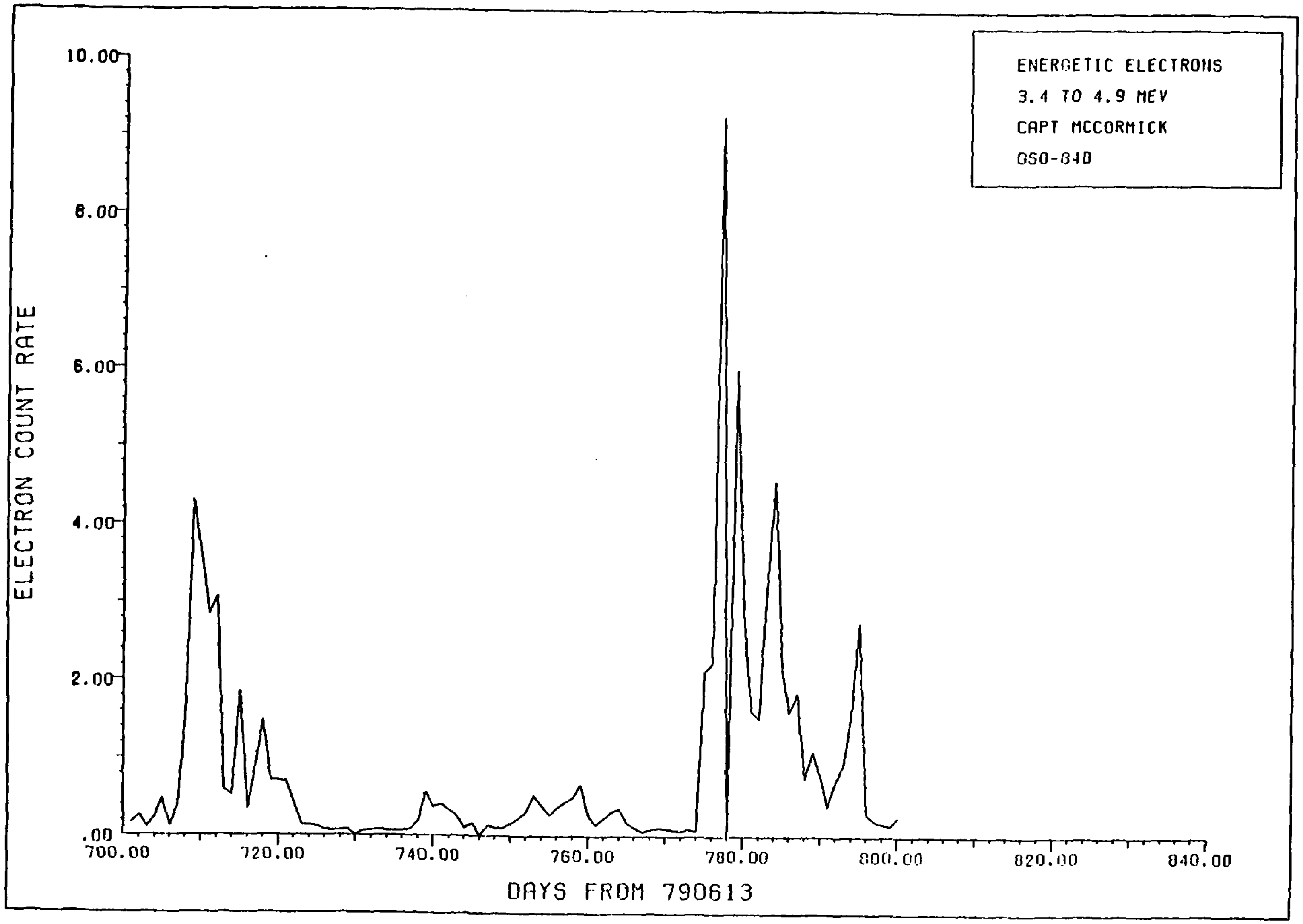
3.4 - 4.9 MeV Electron Flux (7/17/80 - 10/24/80)



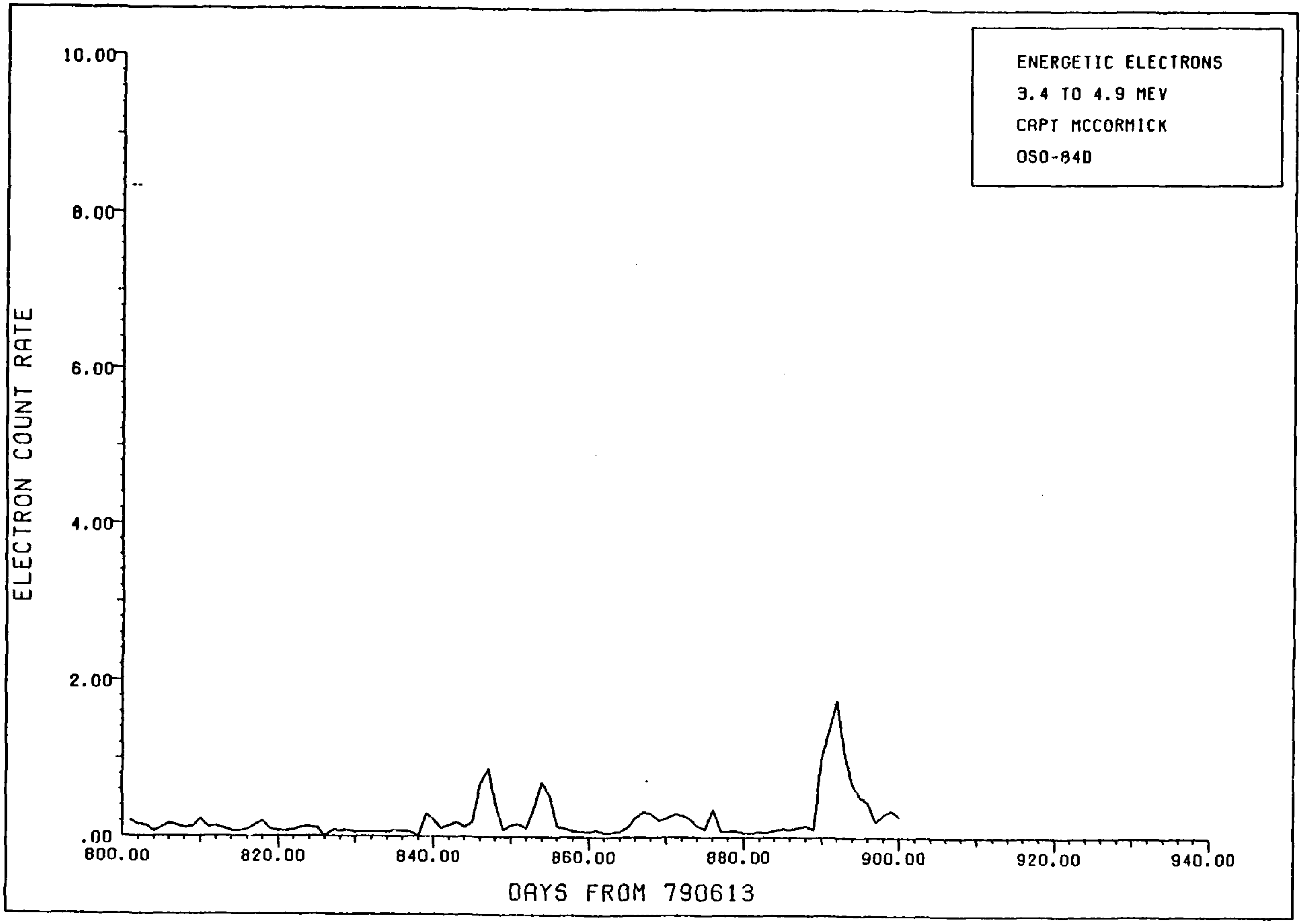
3.4 - 4.9 MeV Electron Flux (10/25/80 - 2/1/81)



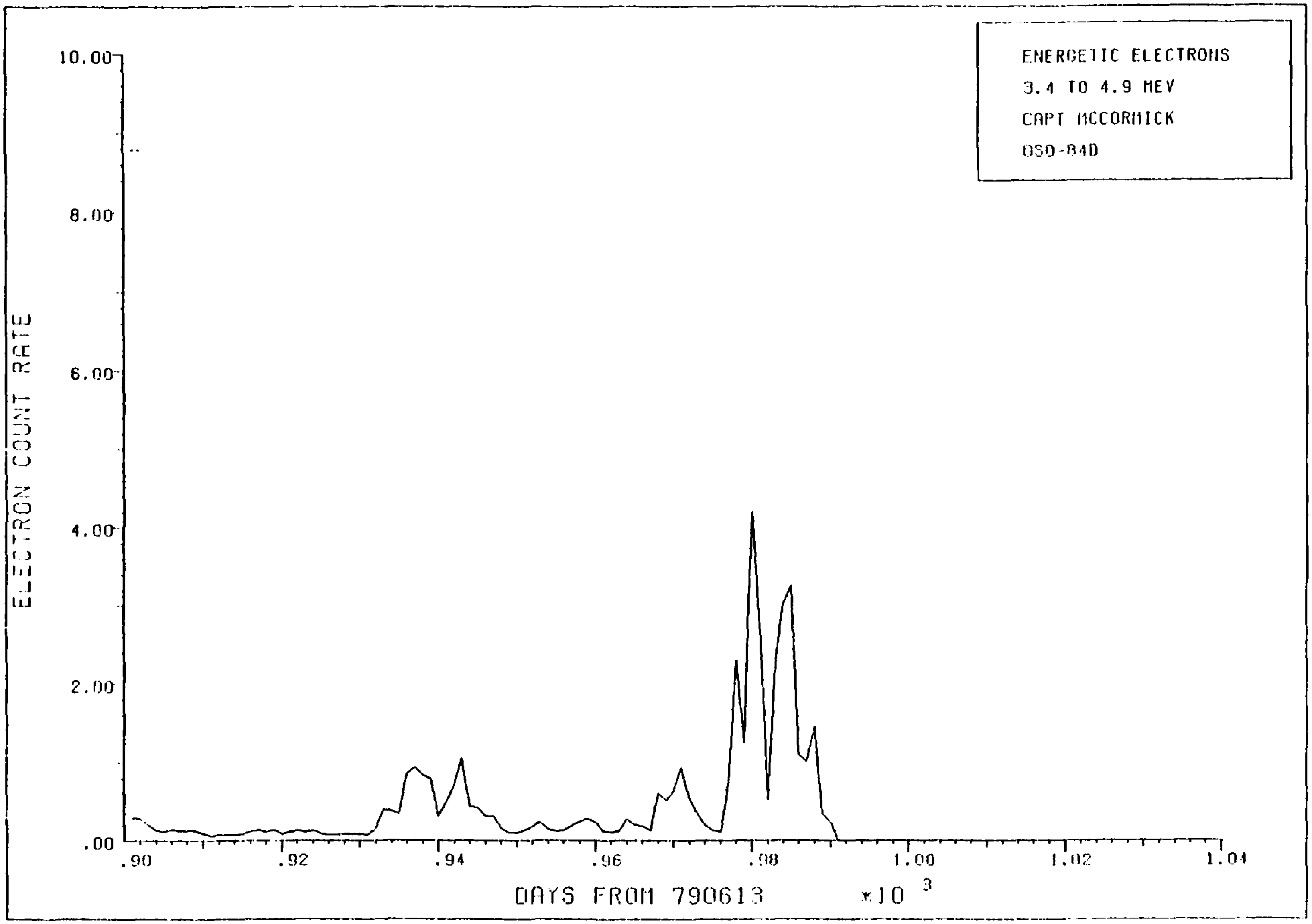
3.4 - 4.9 MeV Electron Flux (2/2/81 - 5/12/81)



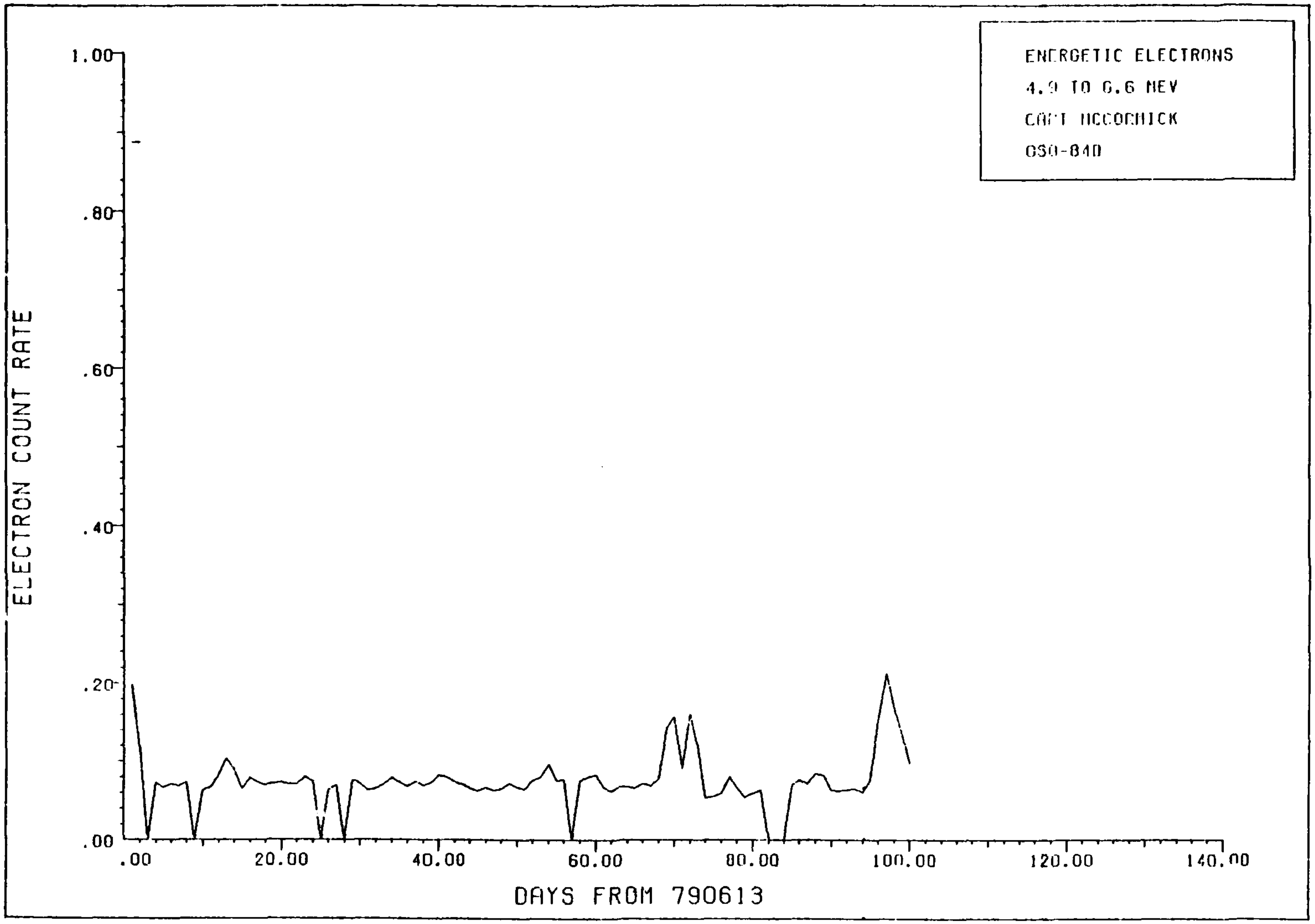
3.4 - 4.9 MeV Electron Flux (5/13/81 - 8/20/81)



3.4 - 4.9 MeV Electron Flux (8/21/81 - 11/28/81)



3.4 - 4.9 MeV Electron Flux (11/29/81 - 3/8/82)



4.9 - 6.6 MeV Electron Flux (6/13/79 - 9/20/79)

AD-A159 295 STATISTICAL ANALYSIS OF ENERGETIC ELECTRONS (12-16 MEV) 2/2
AT GEOSYNCHRONOUS (U) AIR FORCE INST OF TECH
WRIGHT-PATTERSON AFB OH SCHOOL OF ENGI D I MCCORMICK
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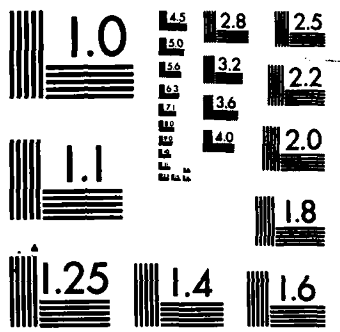
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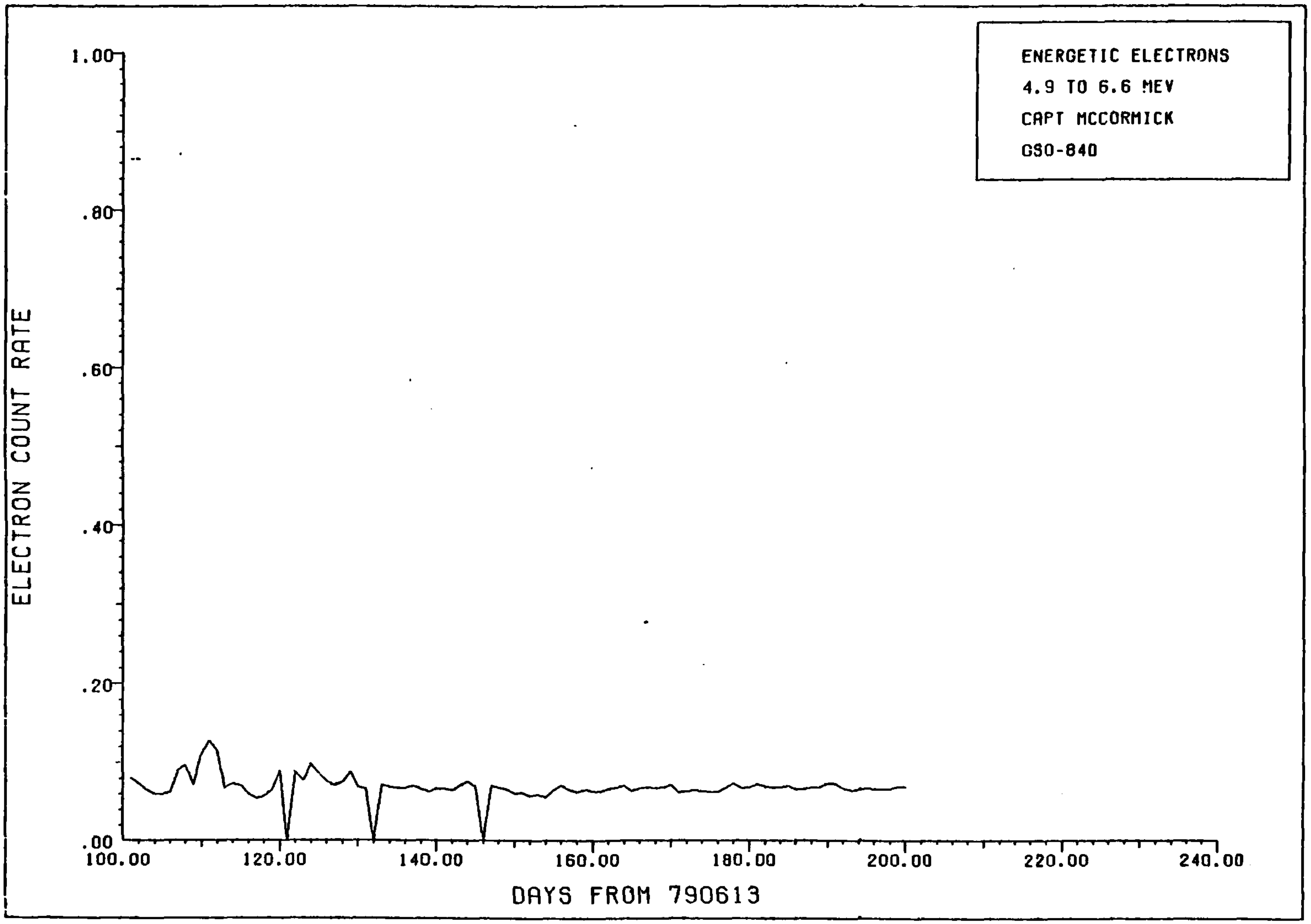
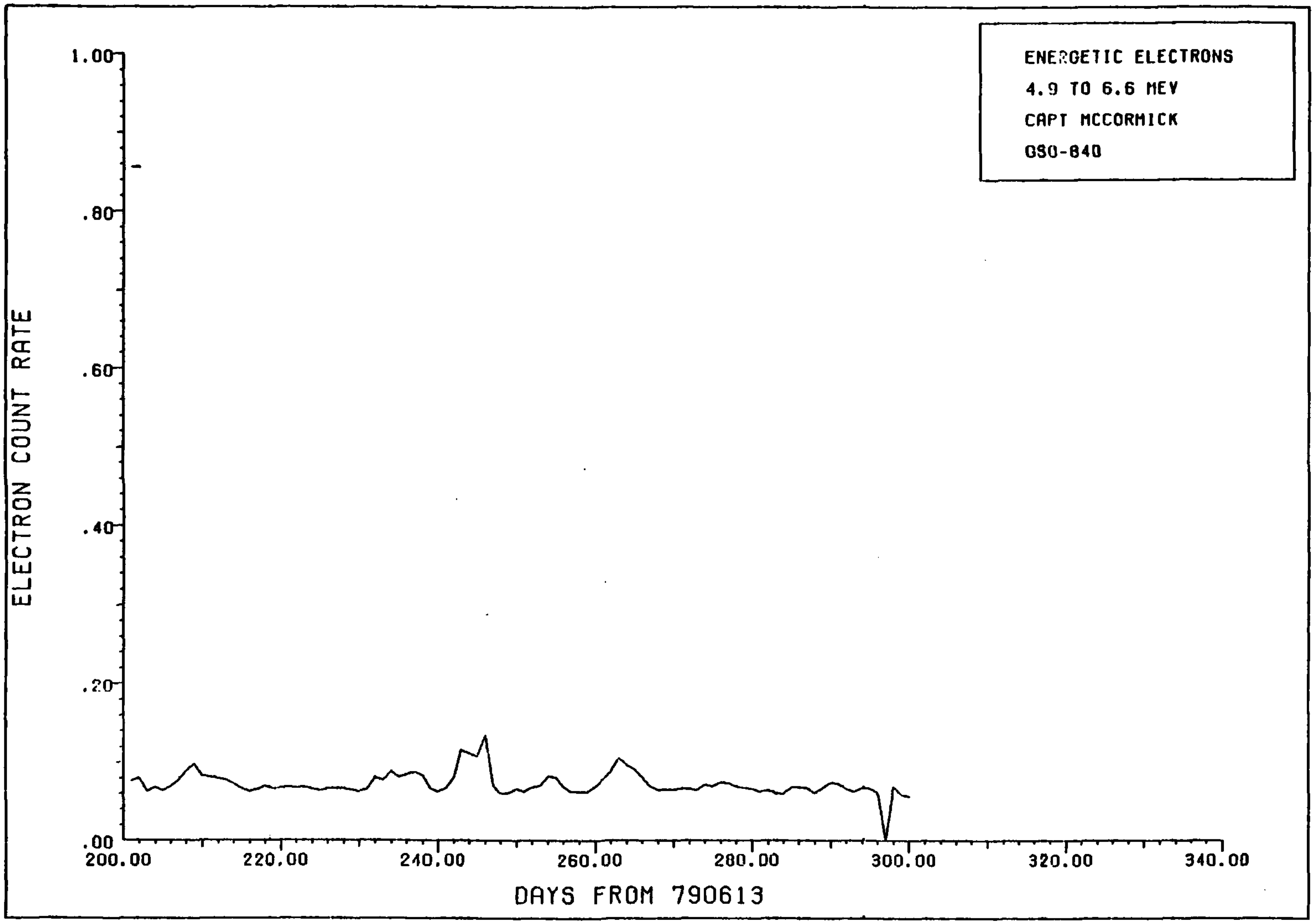
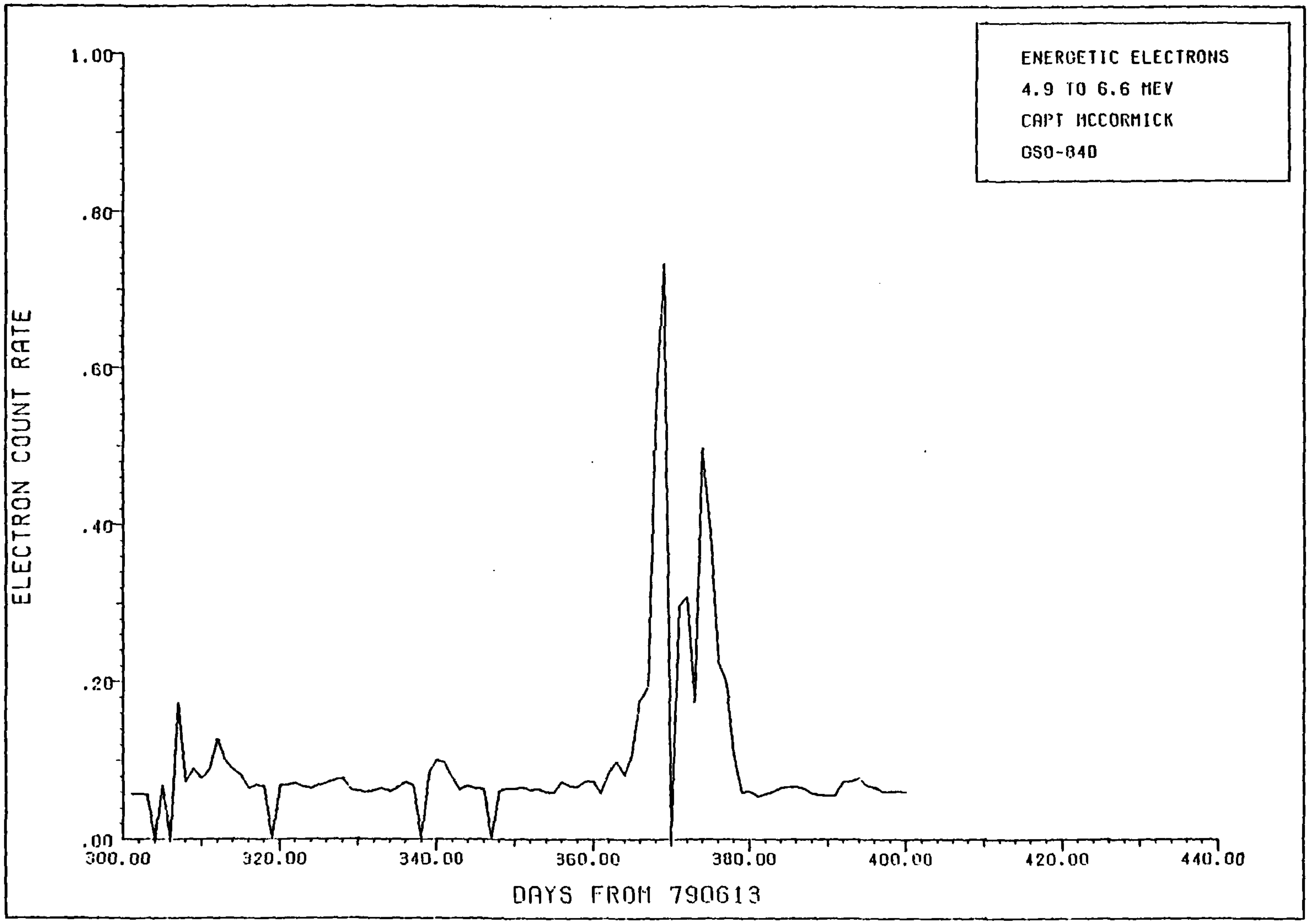


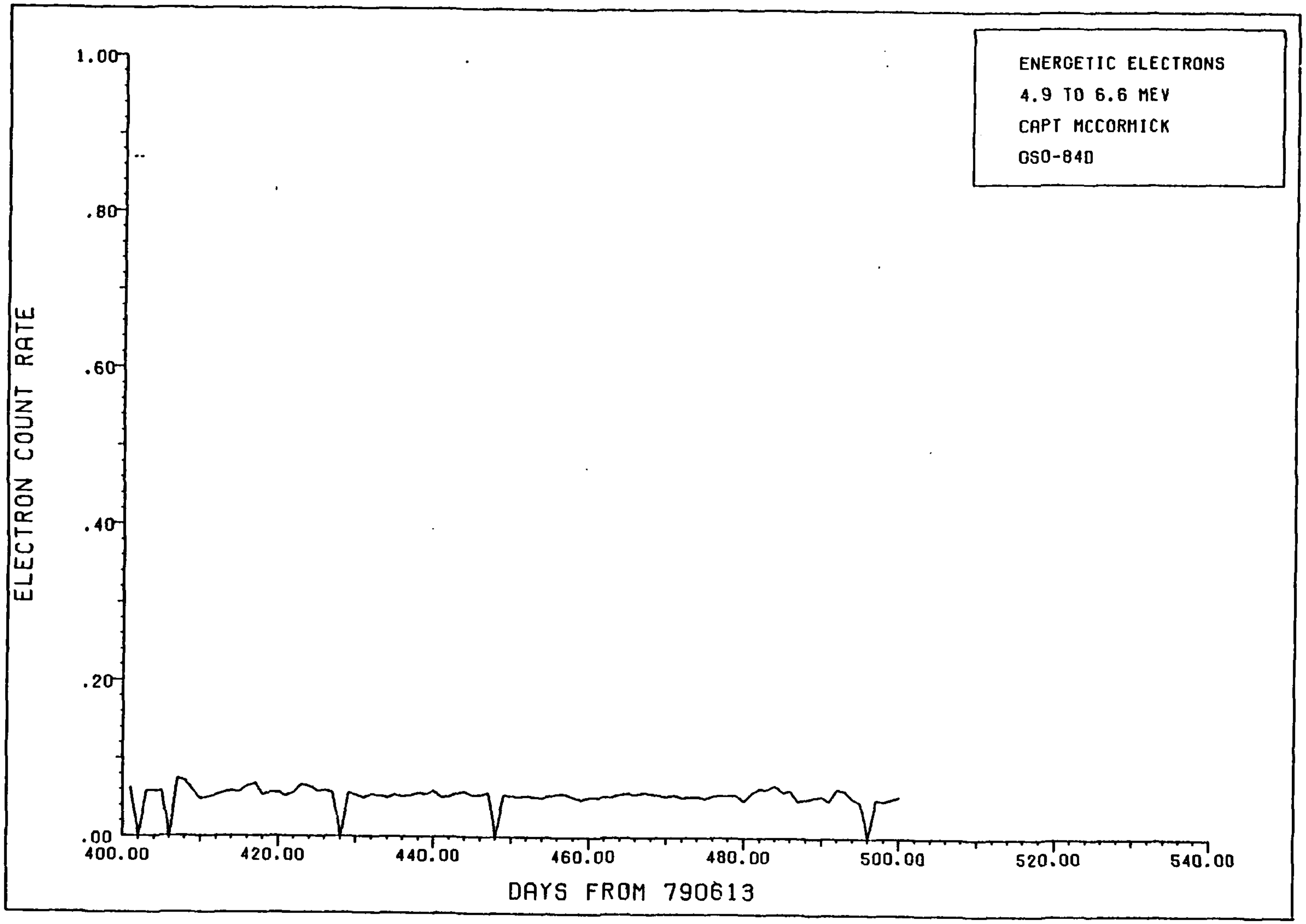
4.9 - 6.6 MeV Electron Flux (9/21/79 - 12/29/79)



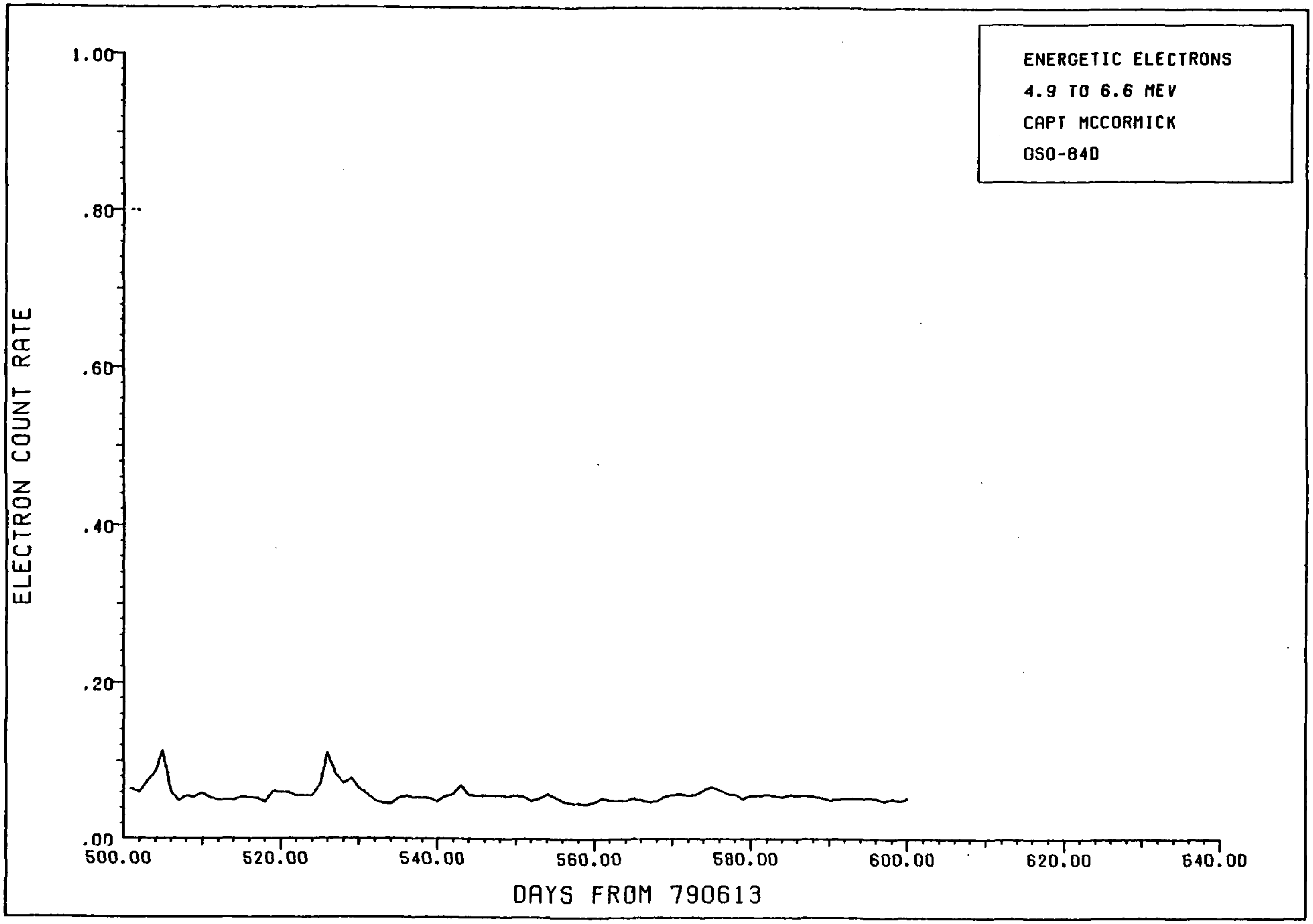
4.9 - 6.6 MeV Electron Flux (12/30/79 - 4/7/80)



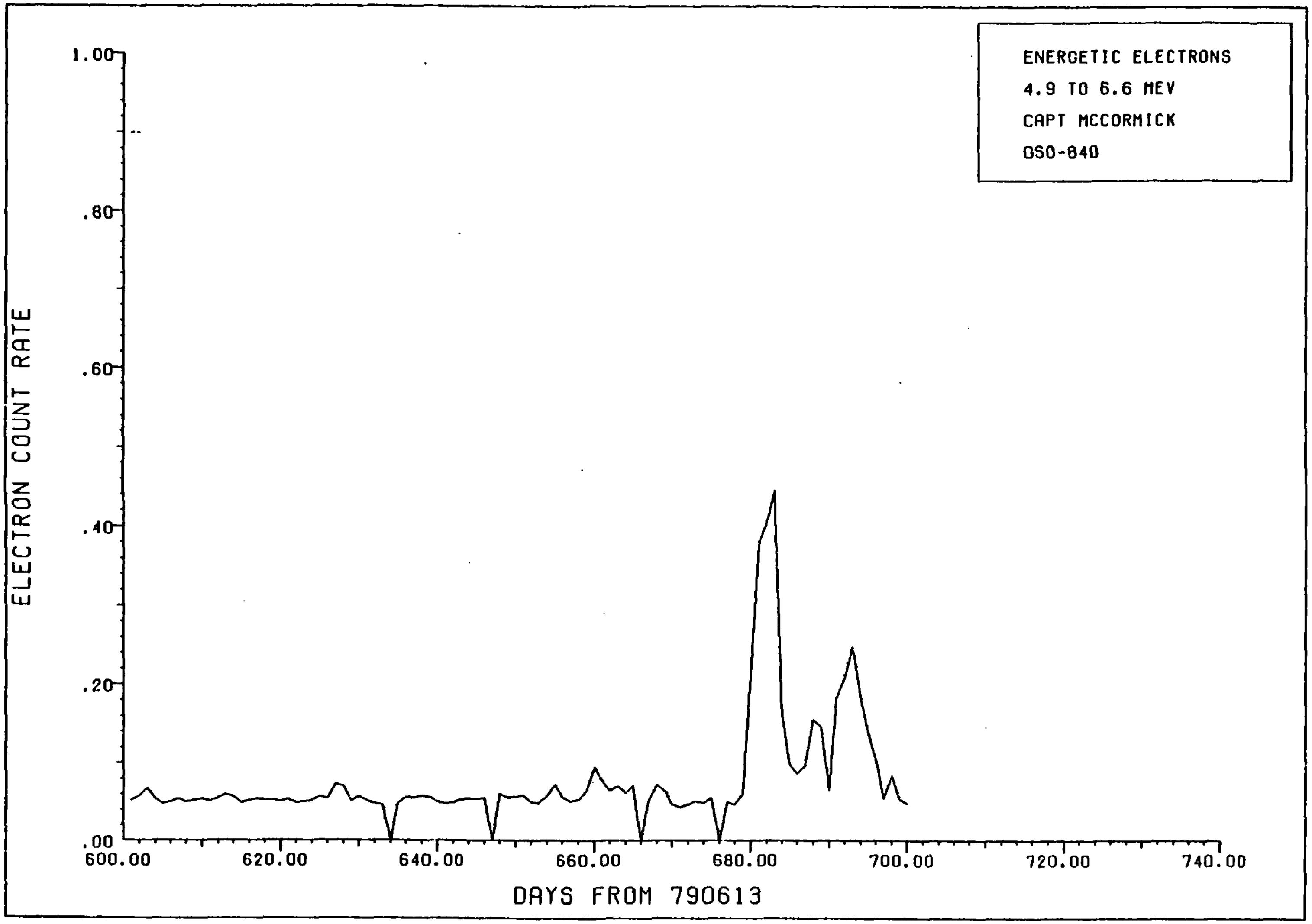
4.9 - 6.6 MeV Electron Flux (4/8/80 - 7/16/80)



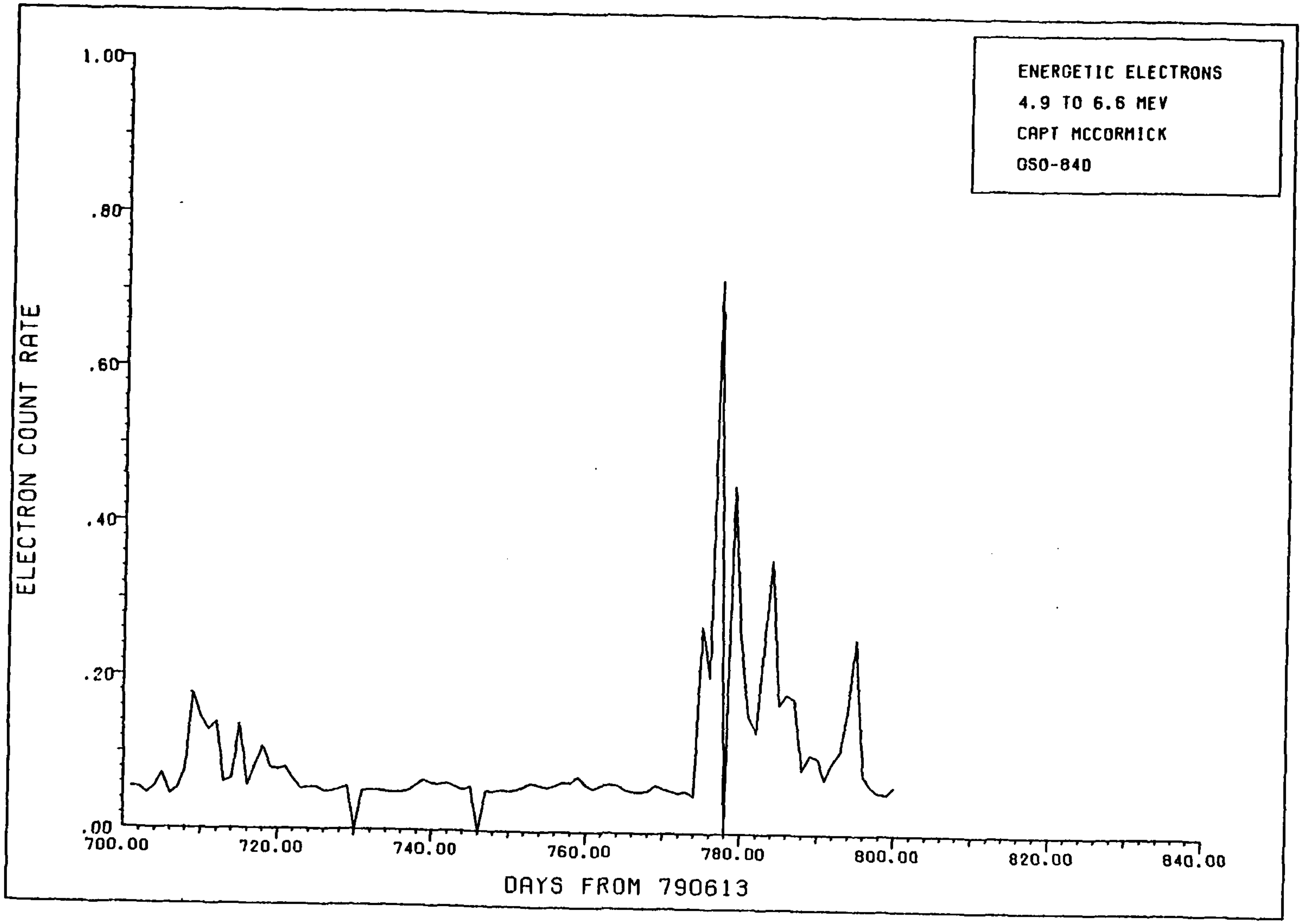
4.9 - 6.6 MeV Electron Flux (7/17/80 - 10/24/80)



4.9 - 6.6 MeV Electron Flux (10/25/80 - 2/1/81)



4.9 - 6.6 MeV Electron Flux (2/2/81 - 5/12/81)



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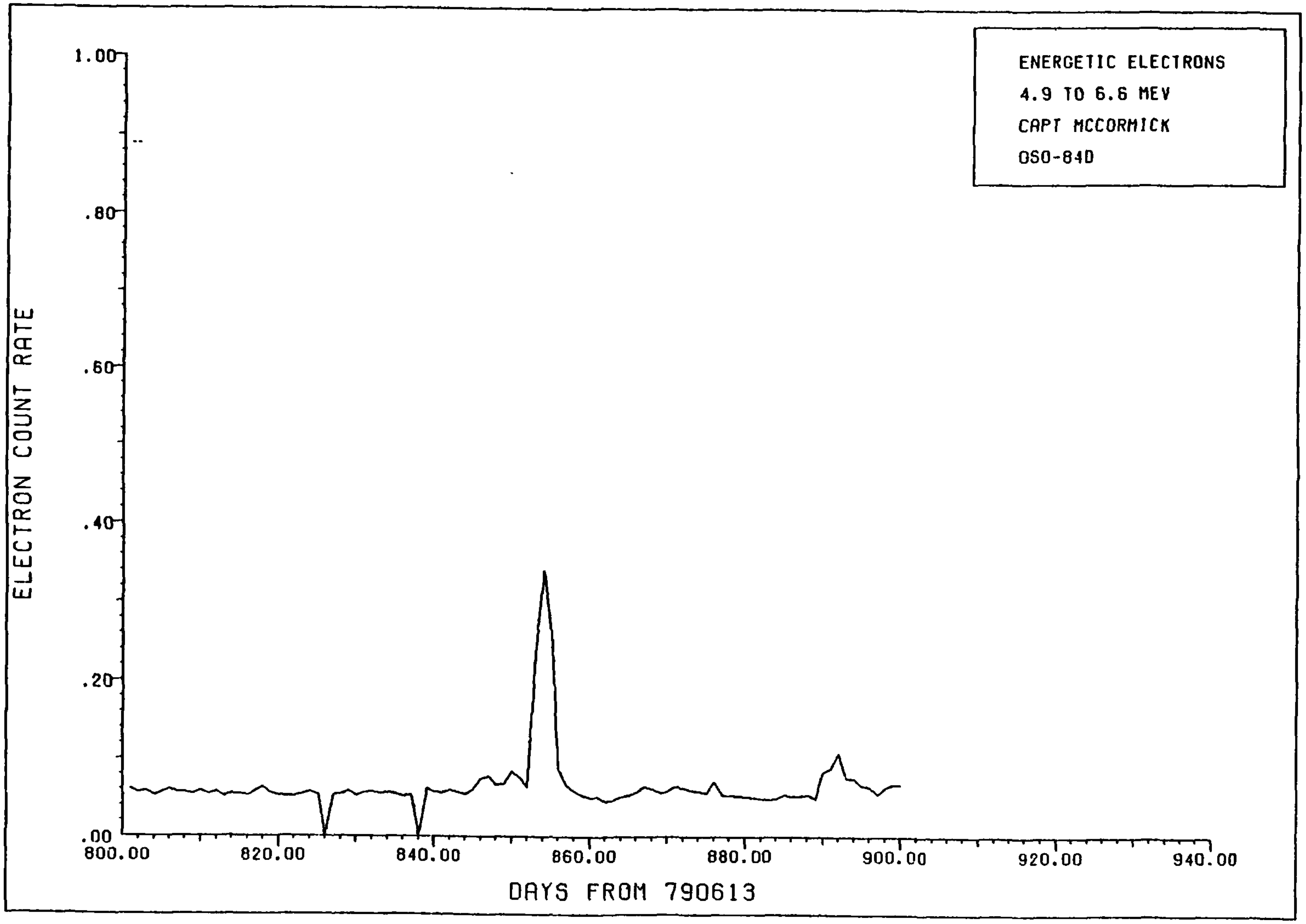
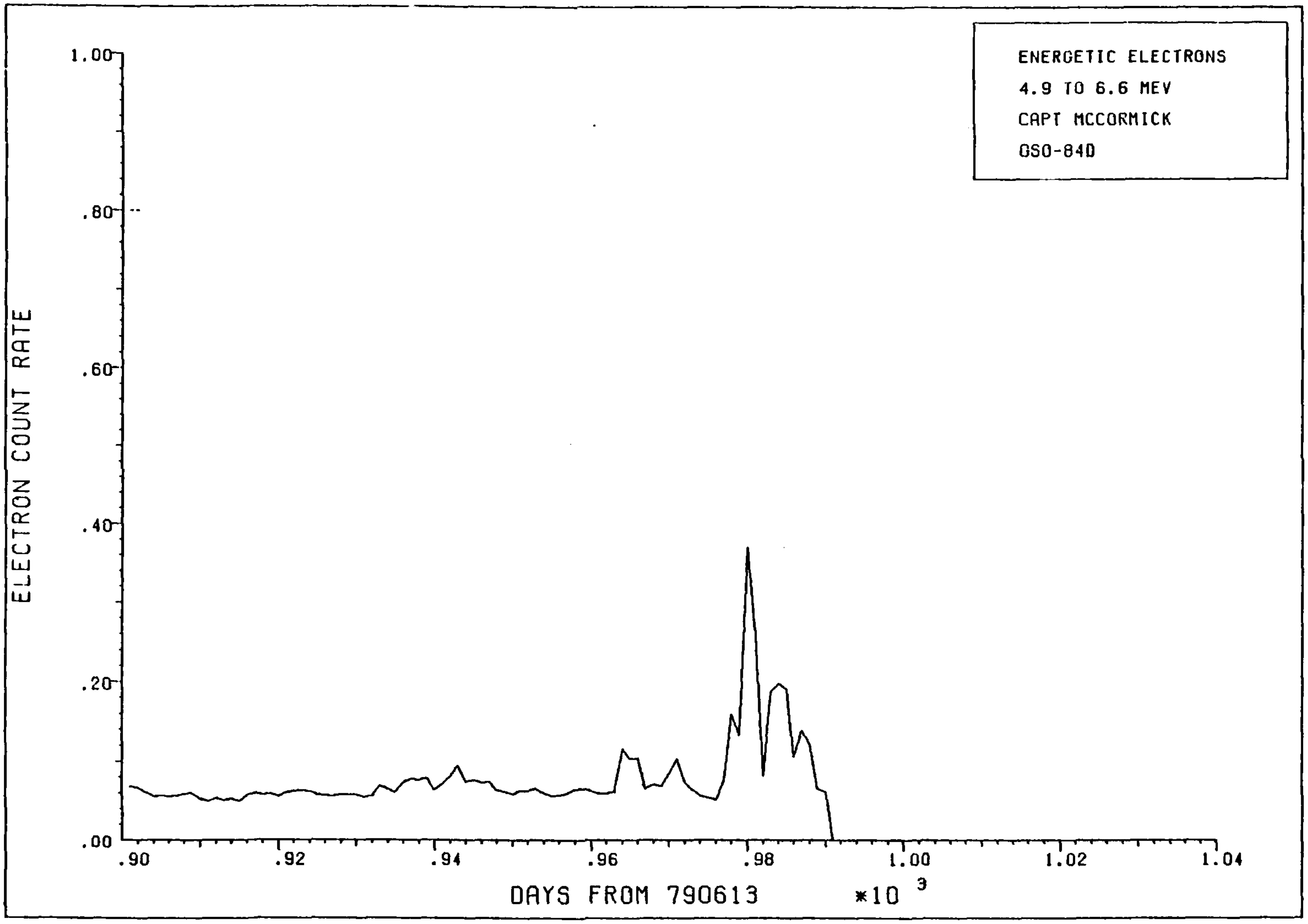
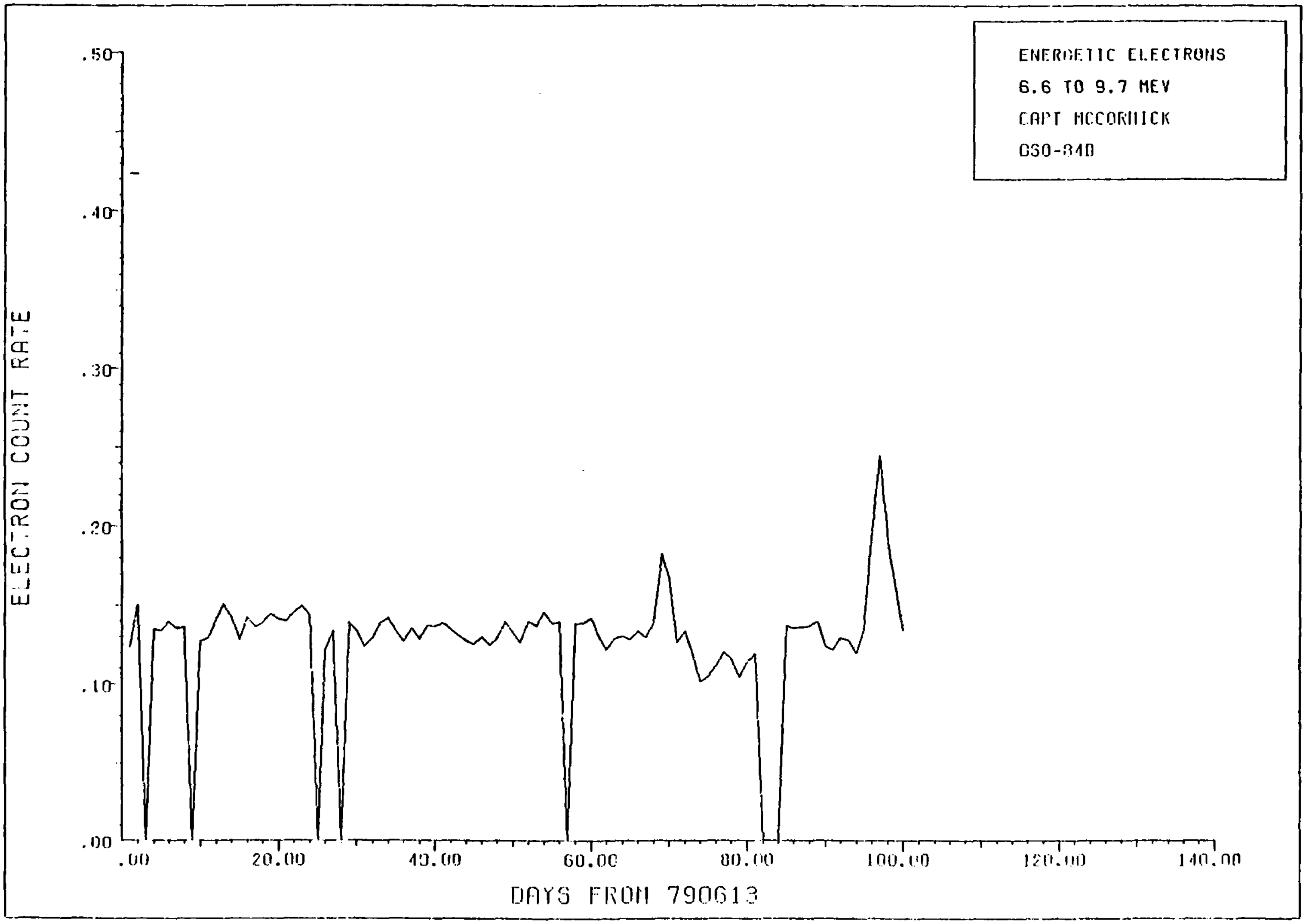


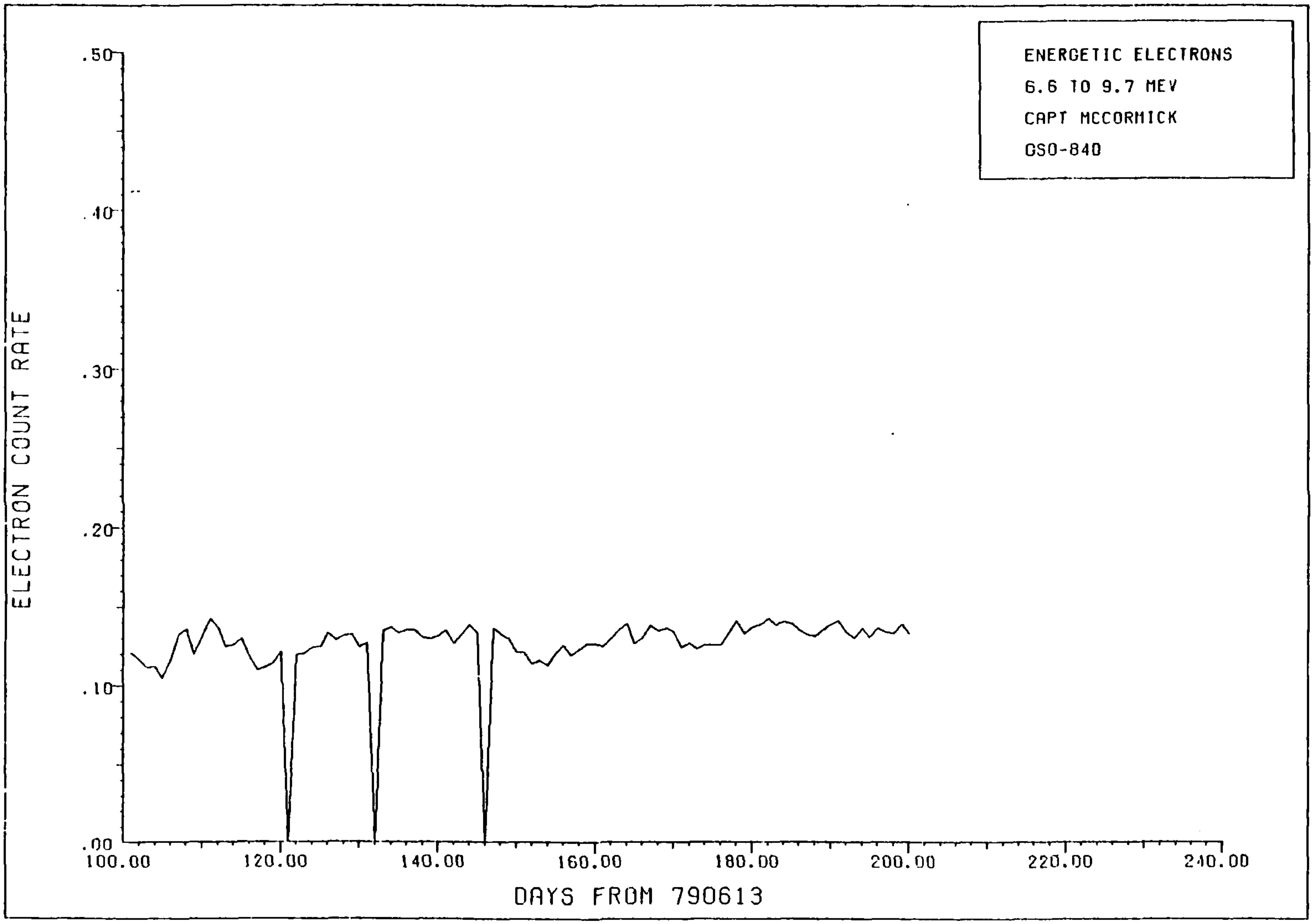
4.9 - 6.6 MeV Electron Flux (8/21/81 - 11/28/81)



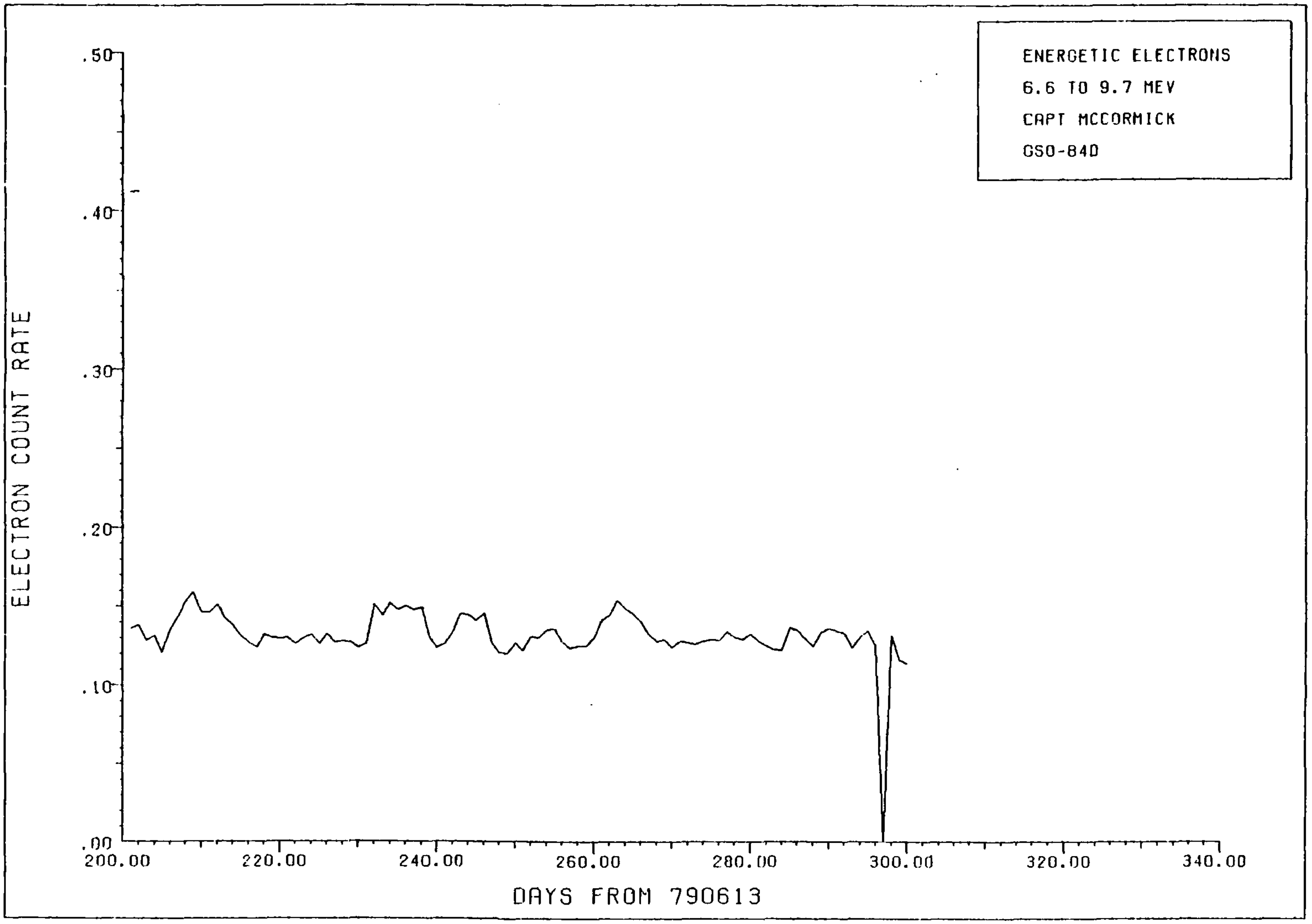
4.9 - 6.6 MeV Electron Flux (11/29/81 - 3/8/82)



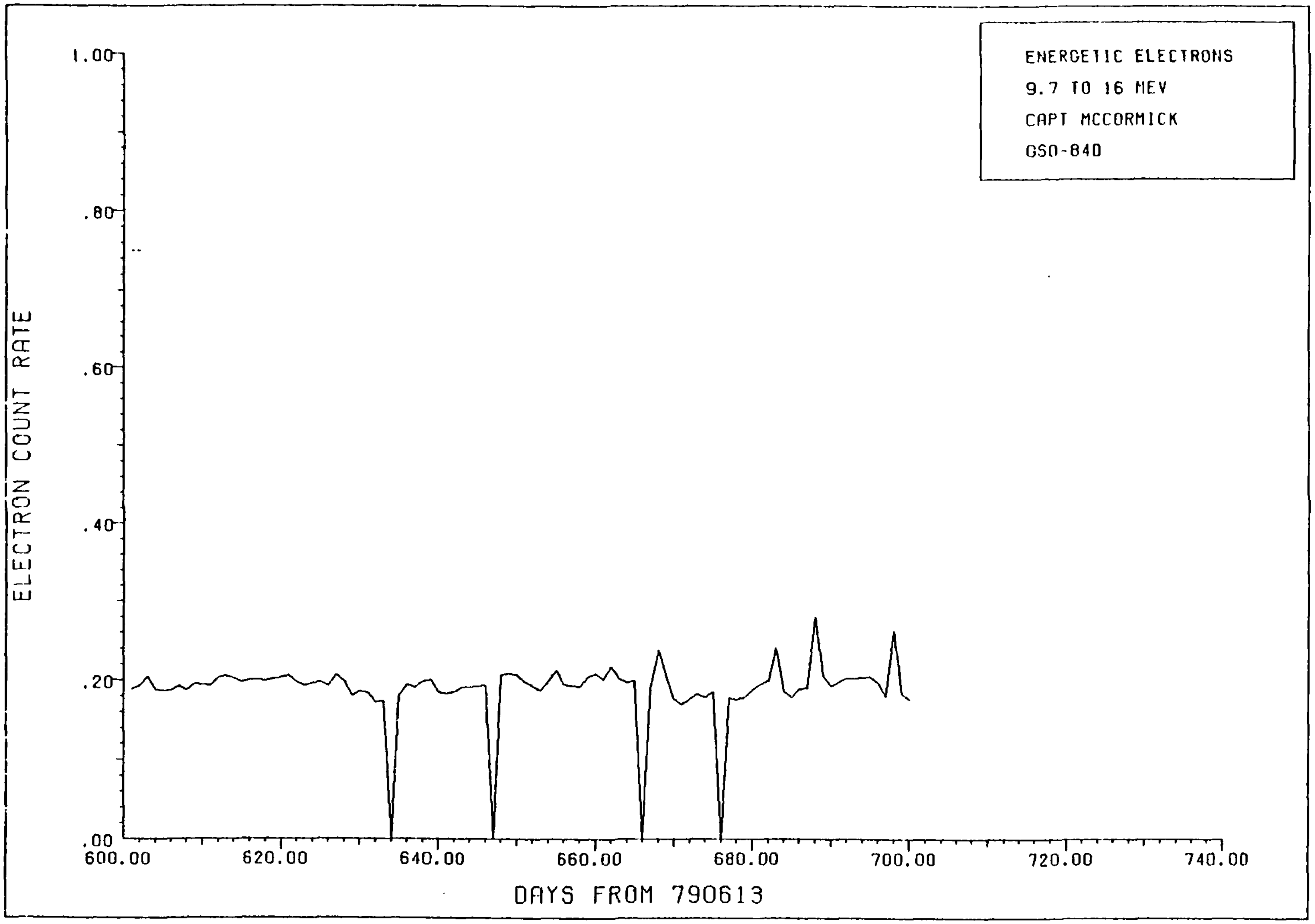
6.6 - 9.7 MeV Electron Flux (6/13/79 - 9/20/79)



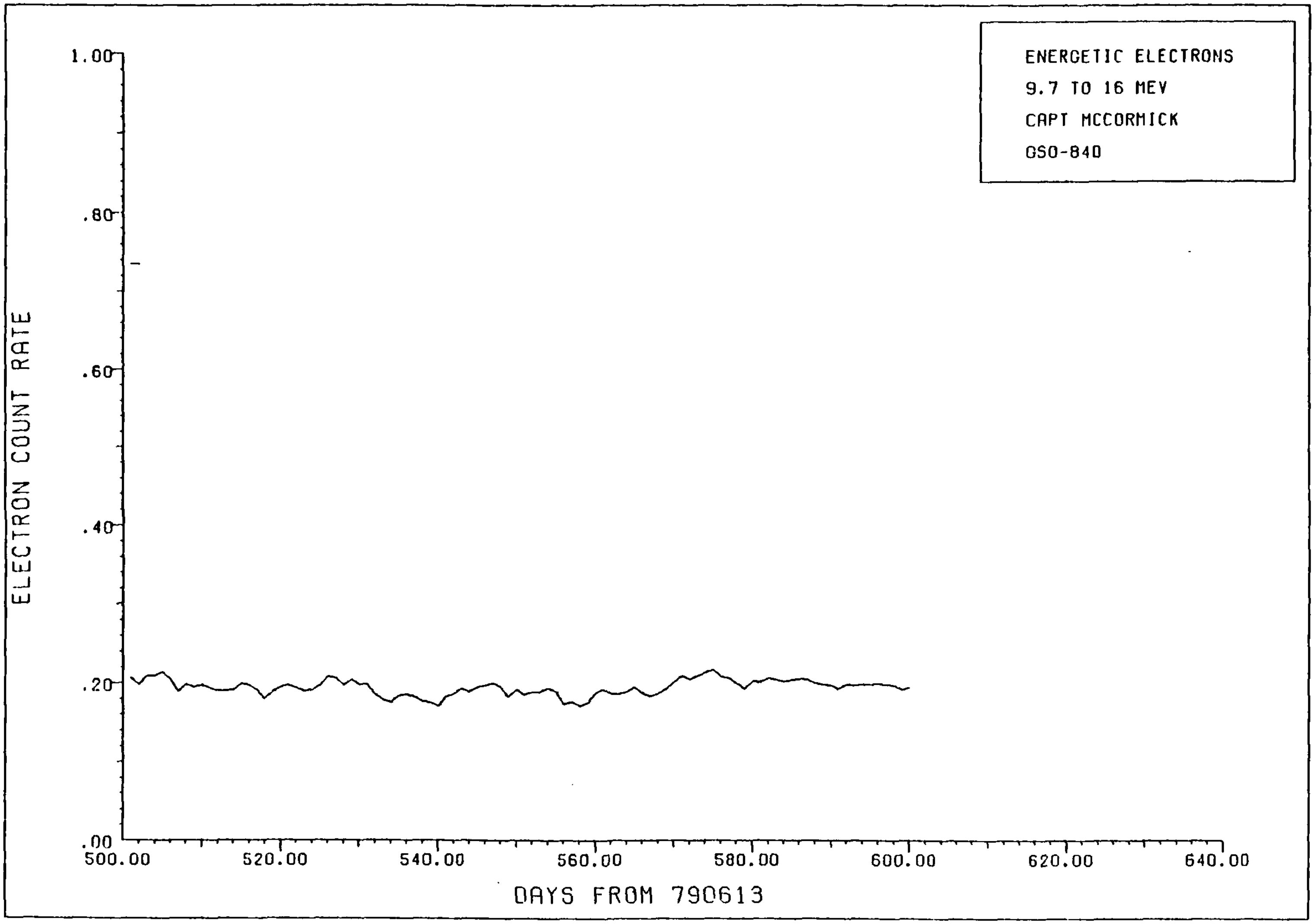
6.6 - 9.7 MeV Electron Flux (9/21/79 - 12/29/79)



6.6 - 9.7 MeV Electron Flux (12/30/79 - 4/7/80)



9.7 - 16 MeV Electron Flux (2/2/81 - 5/12/81)



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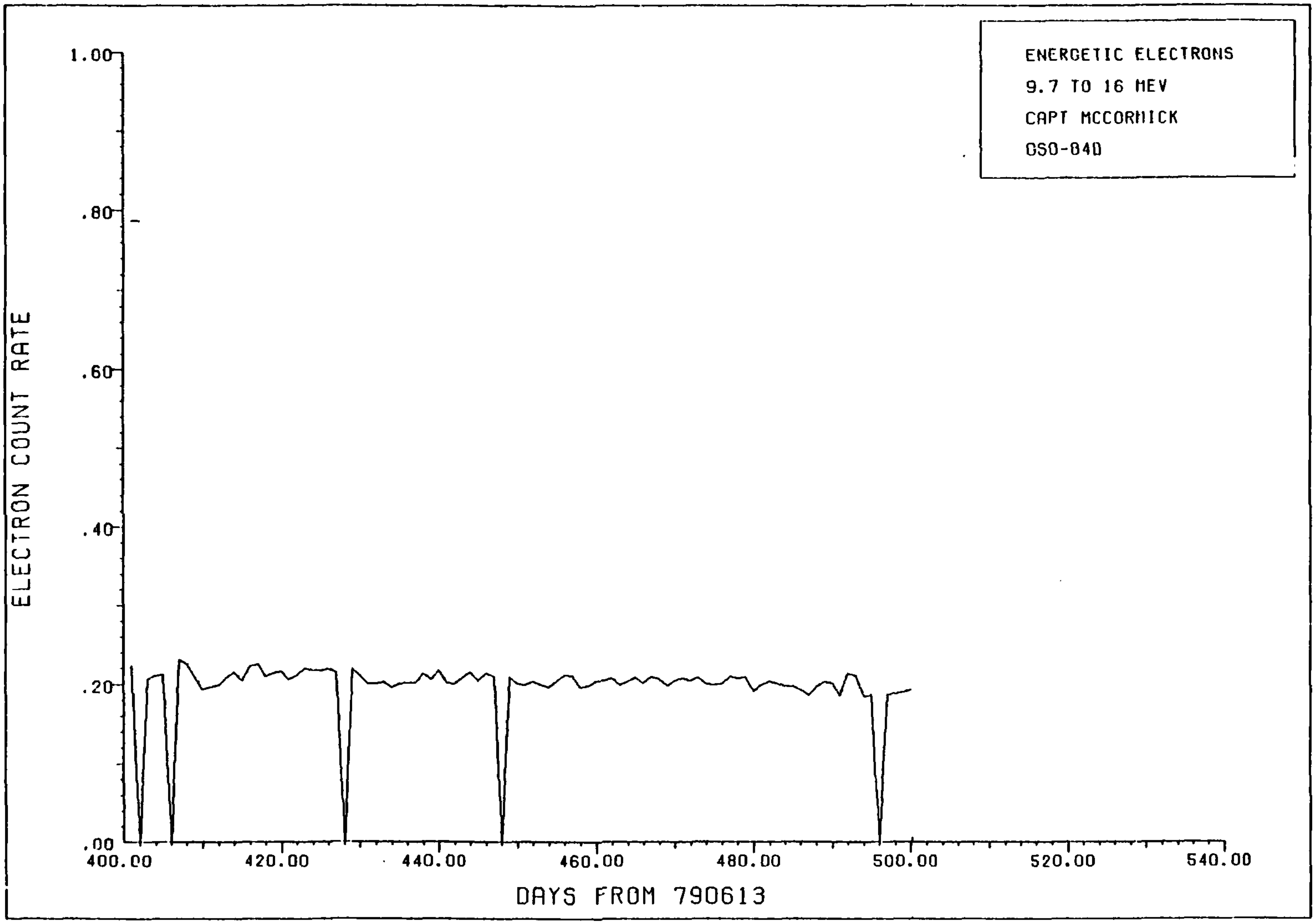

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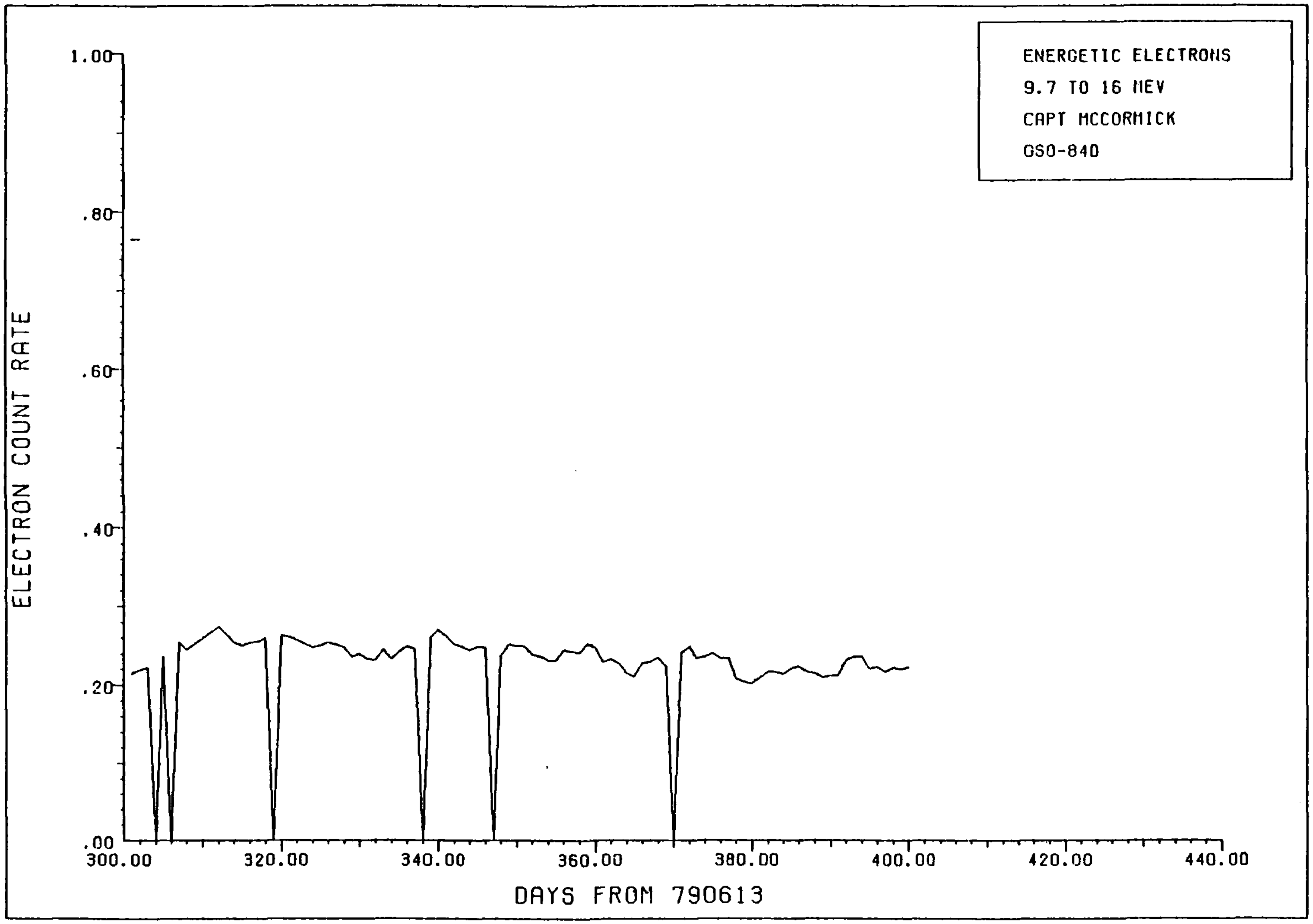

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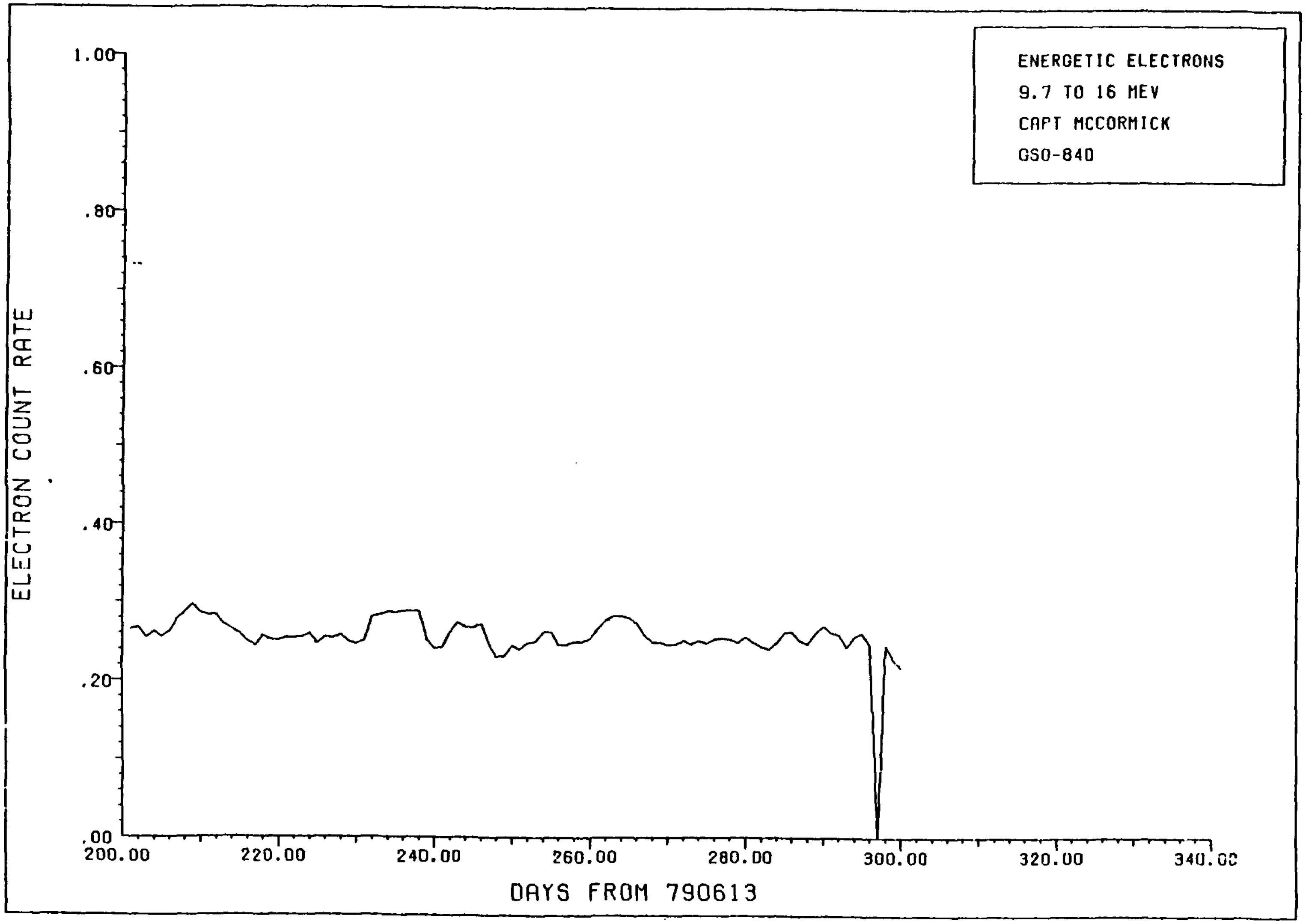

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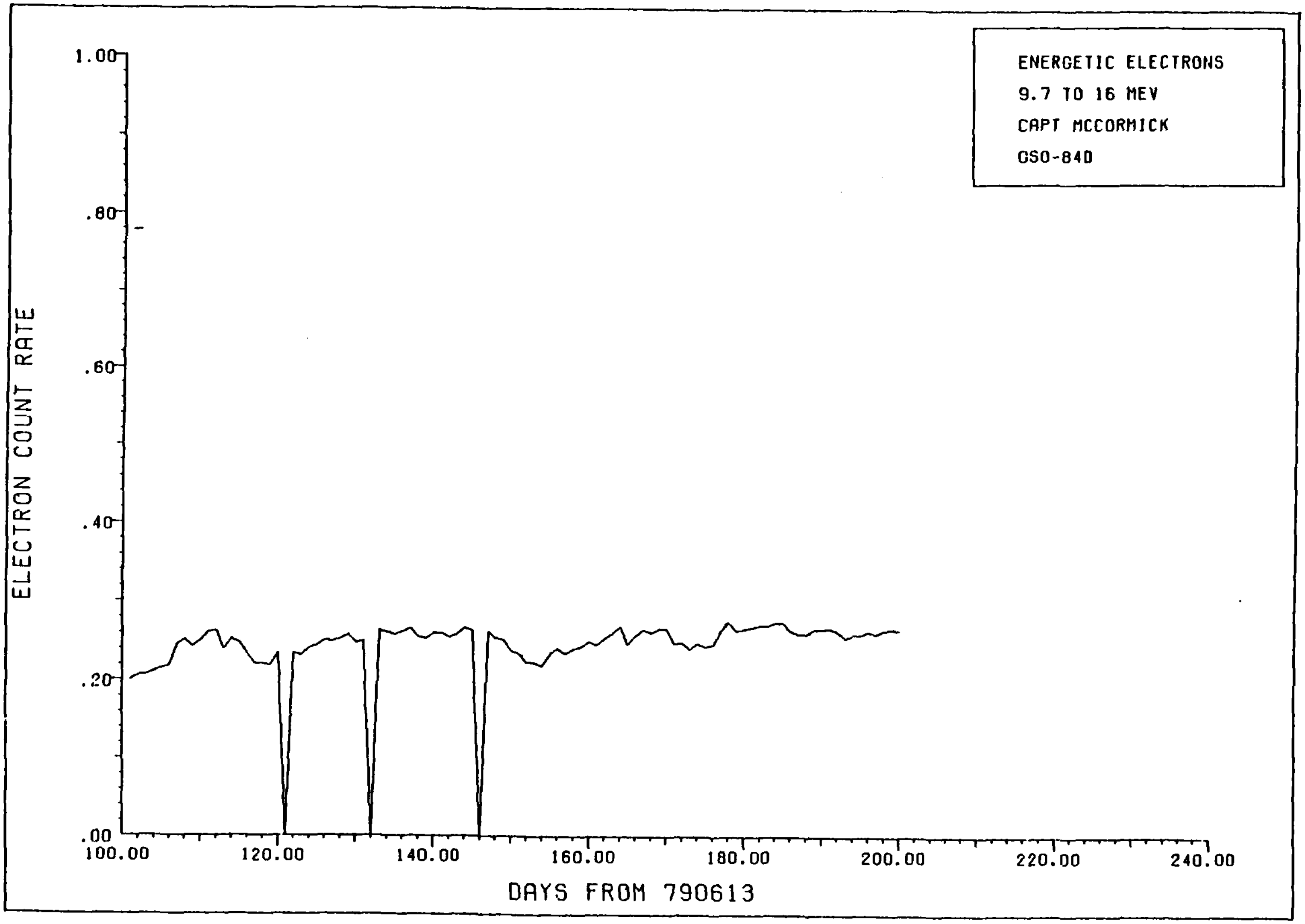

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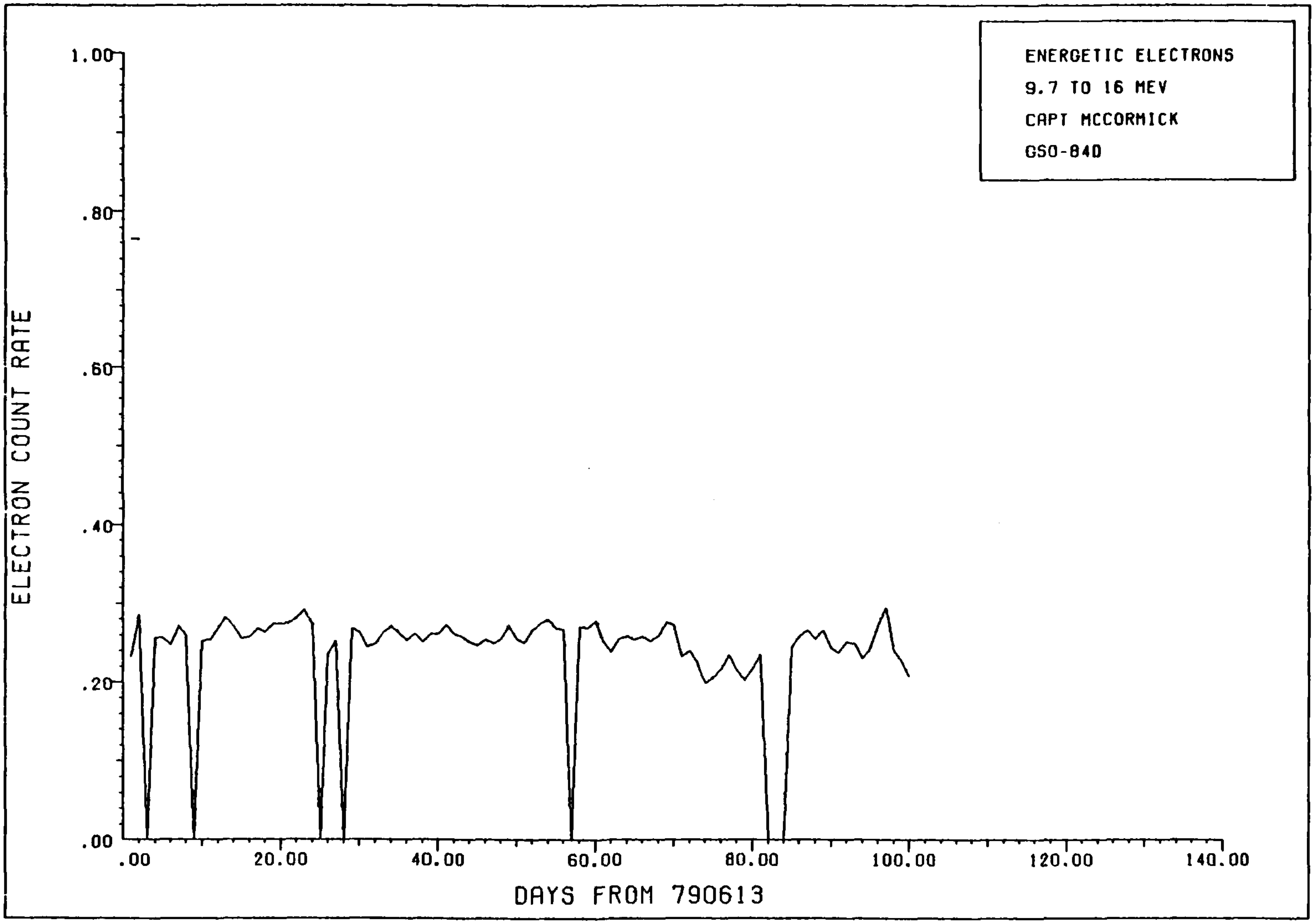

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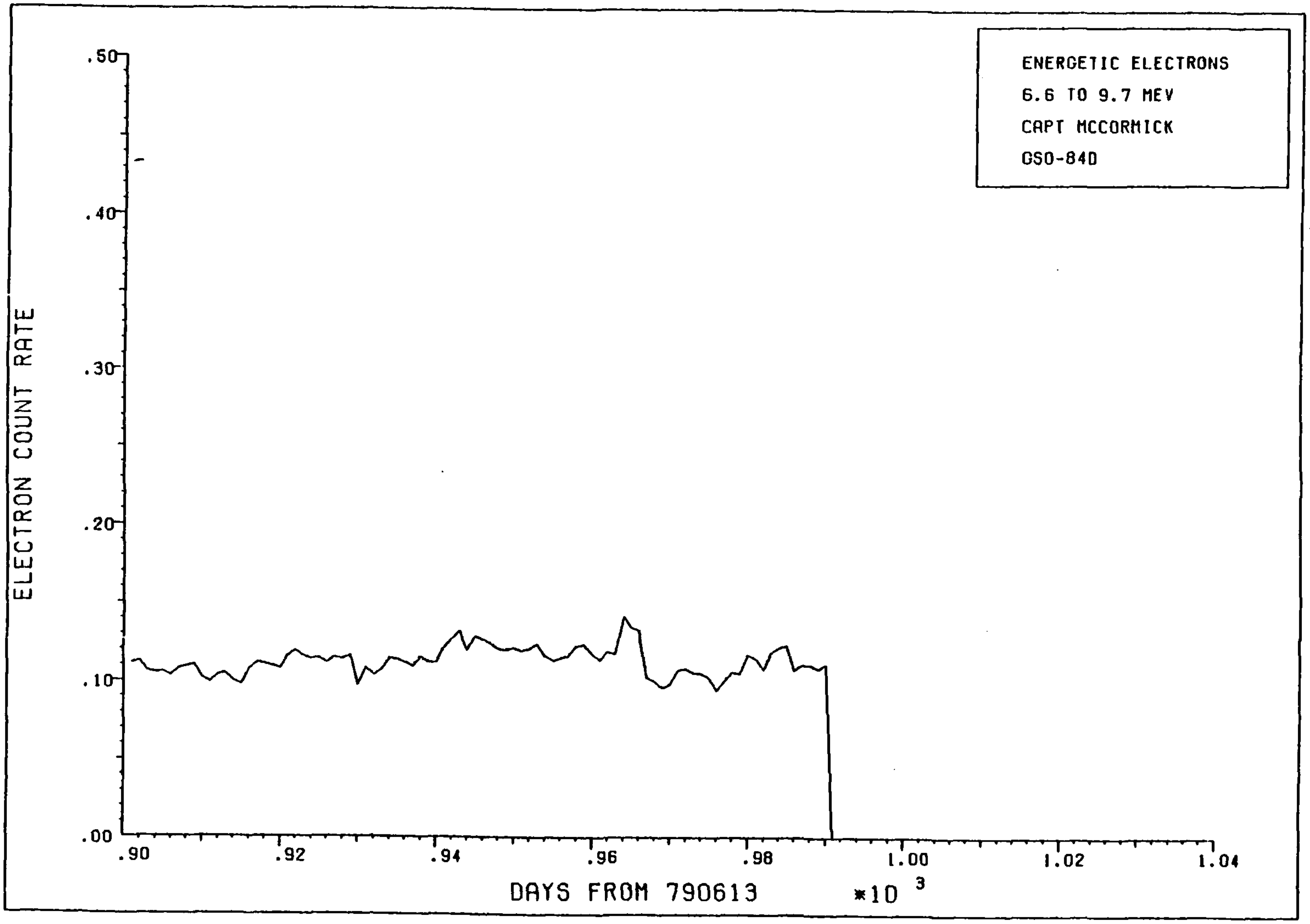

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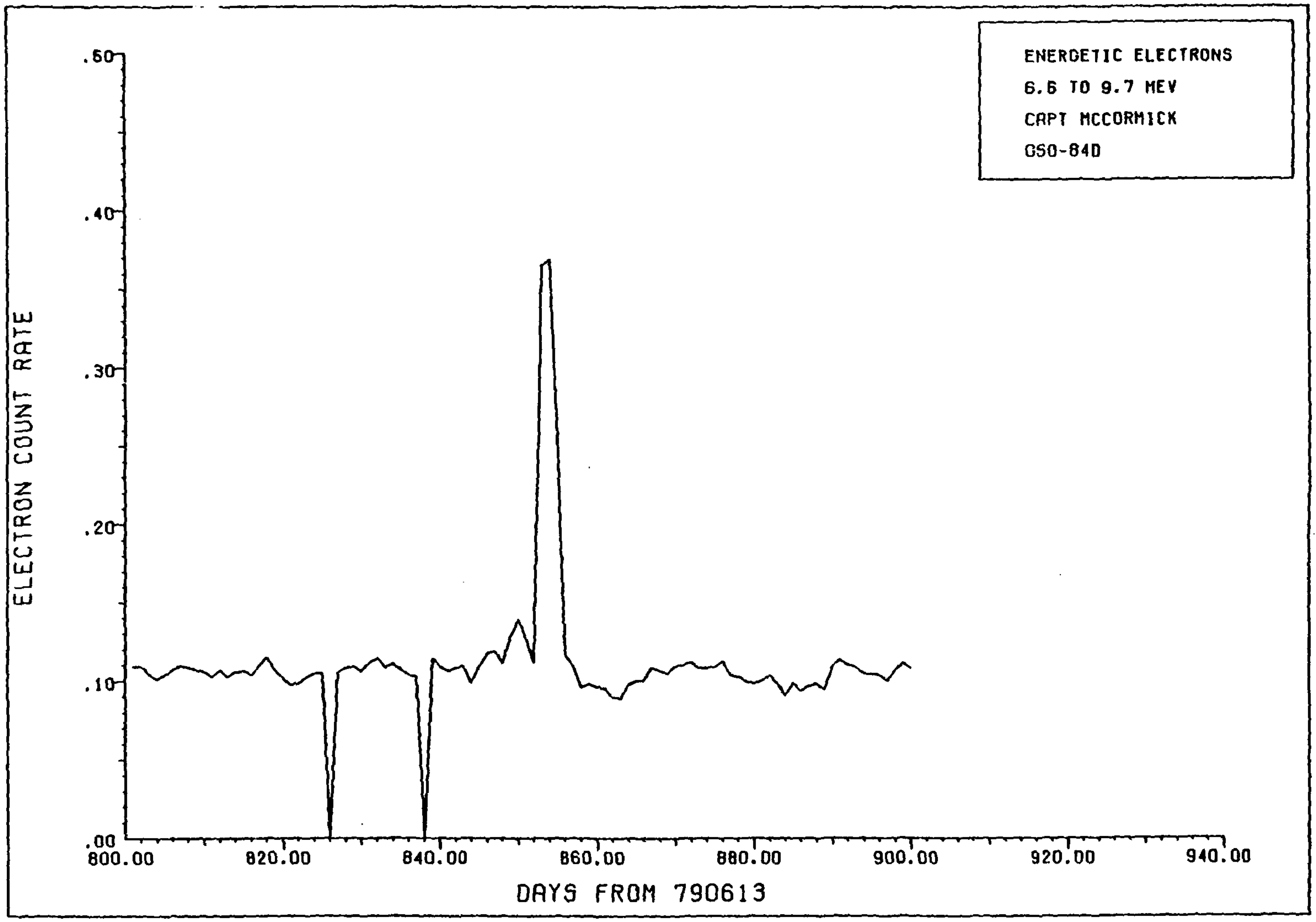

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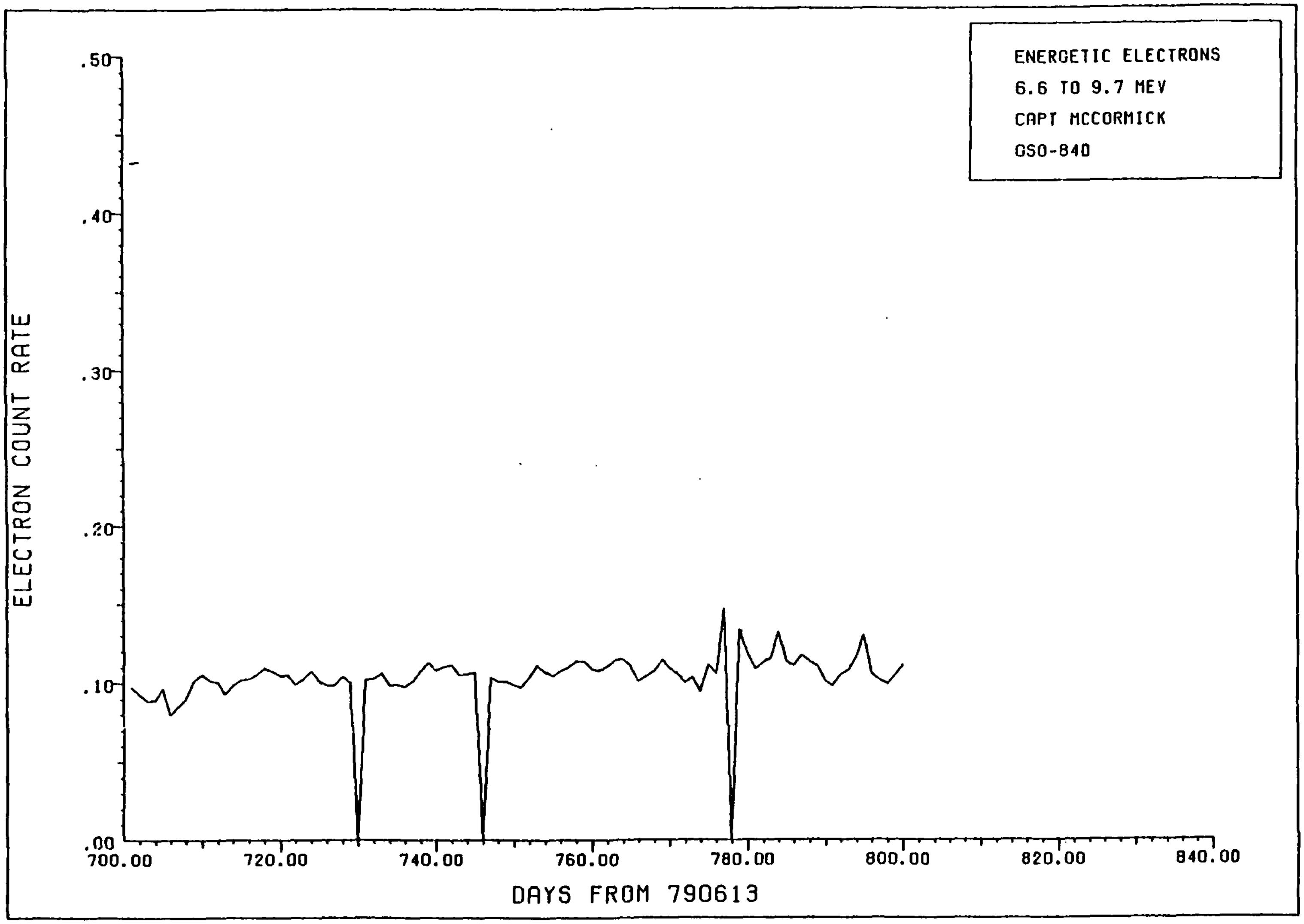

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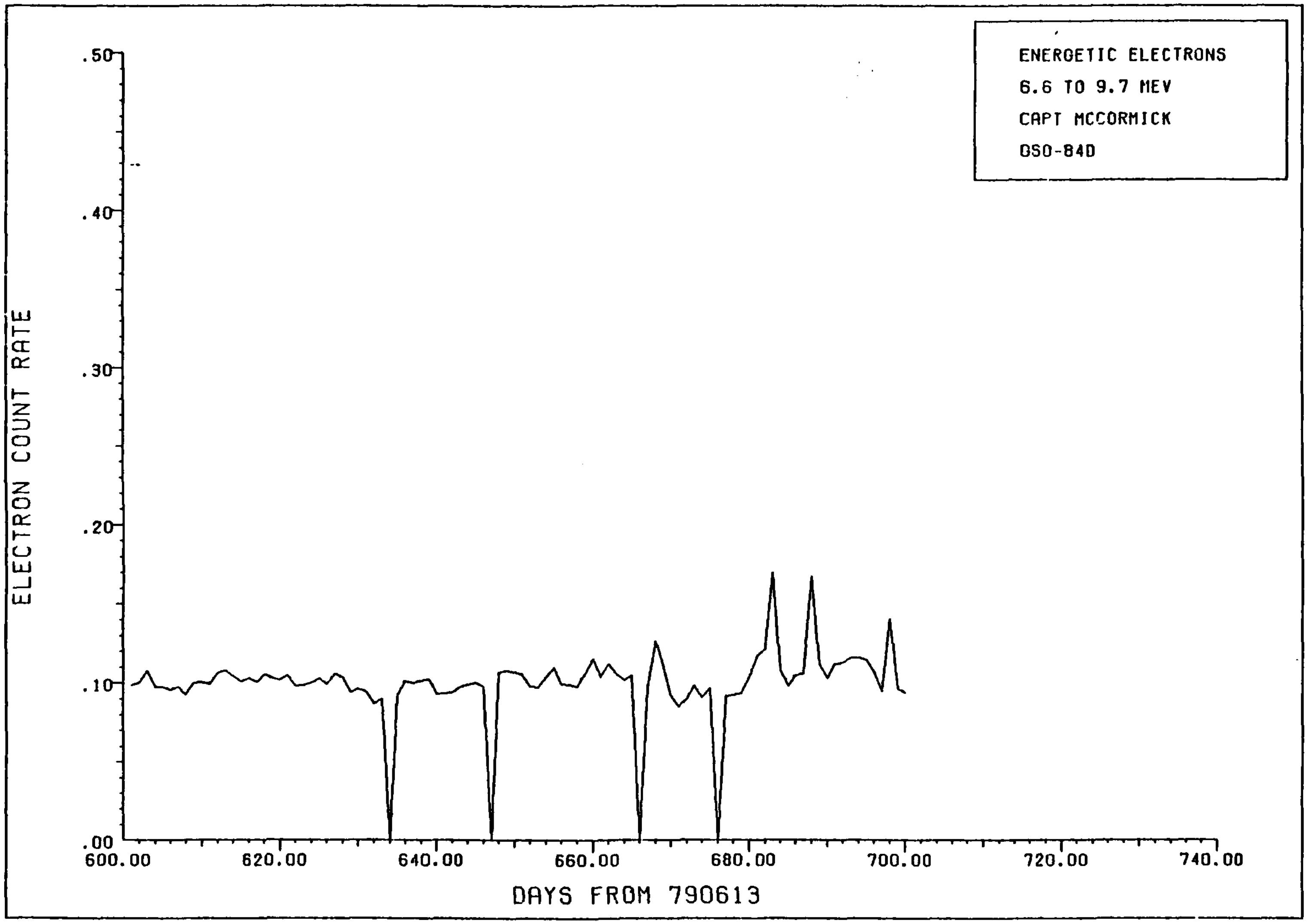

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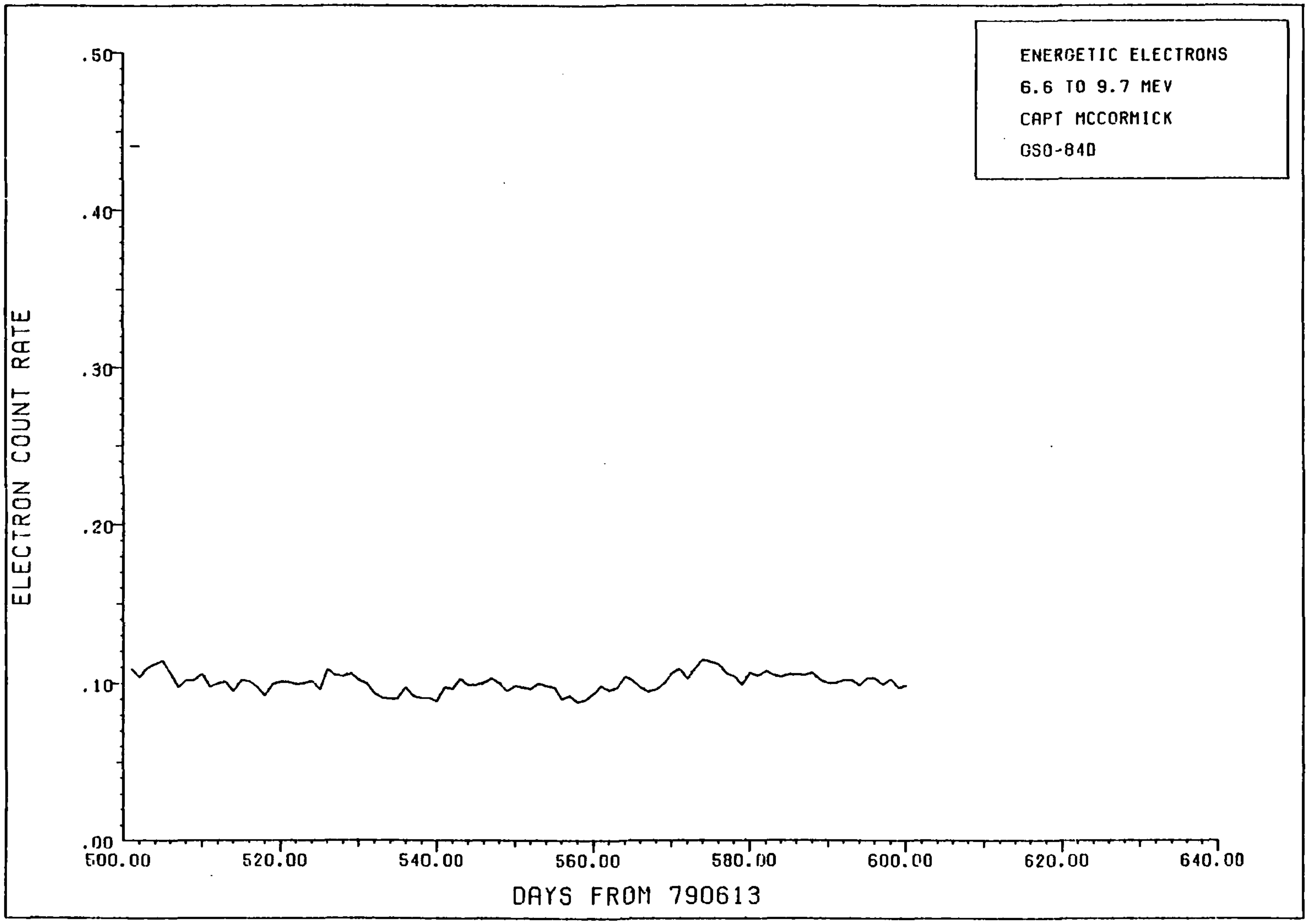

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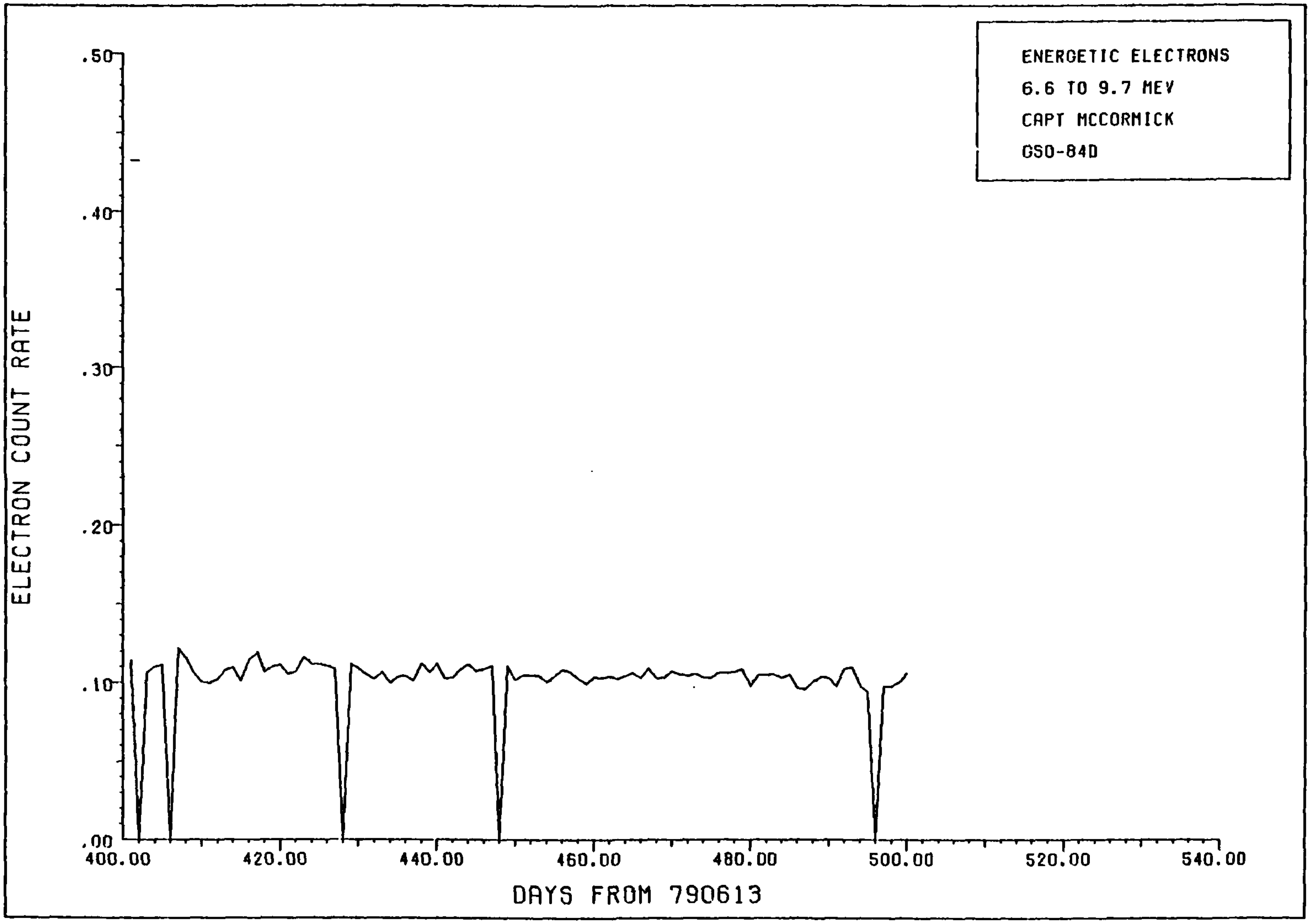

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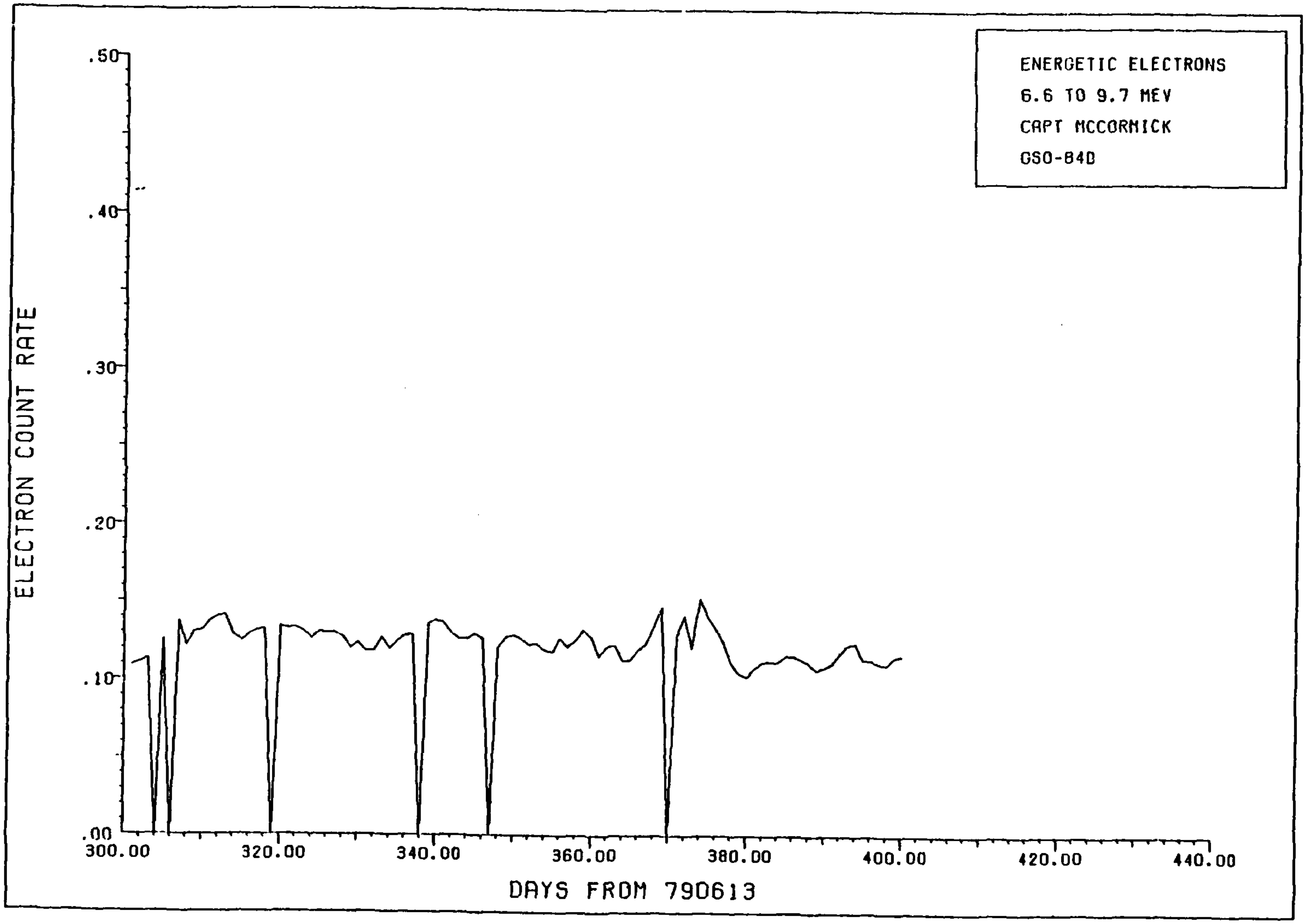

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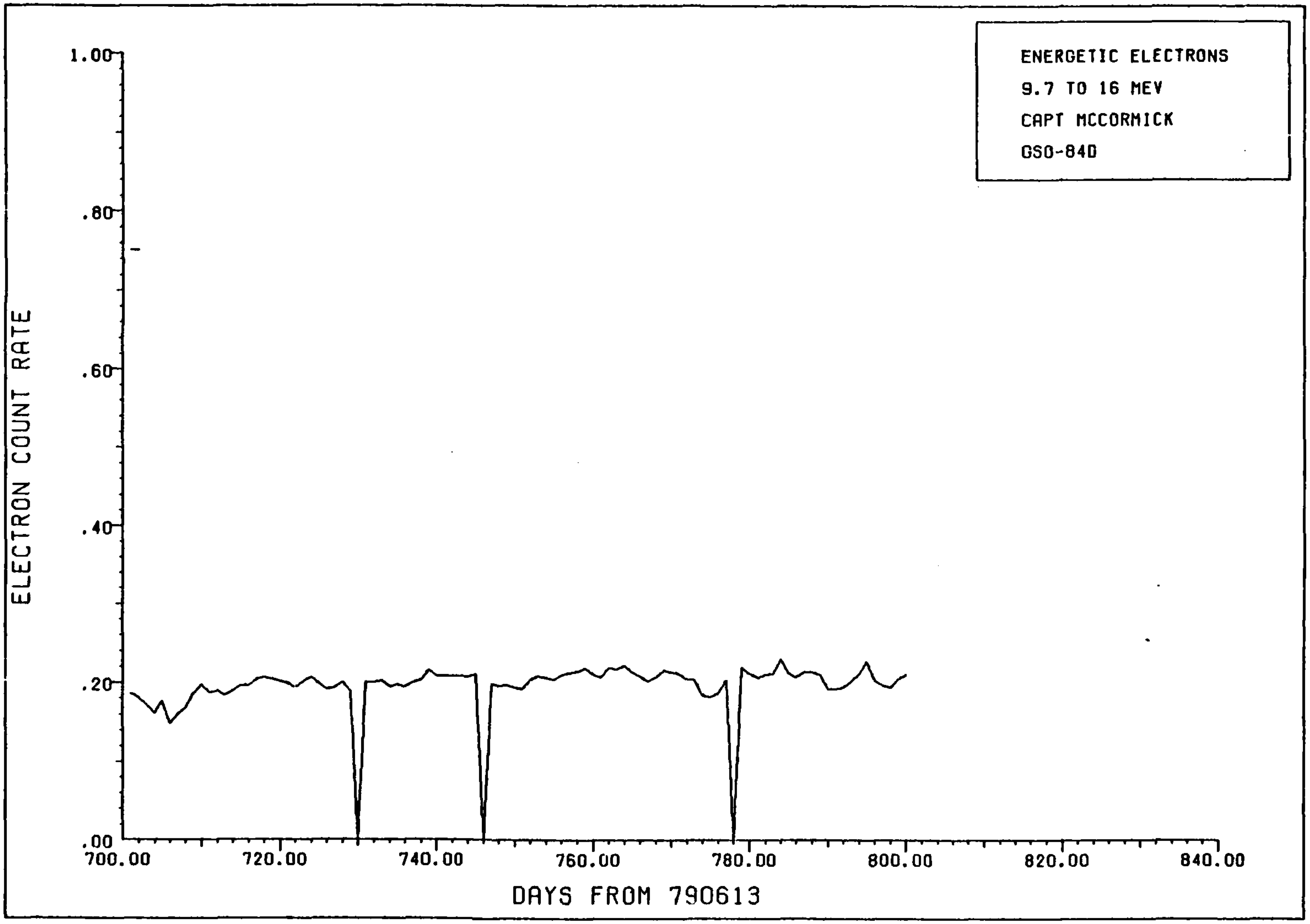

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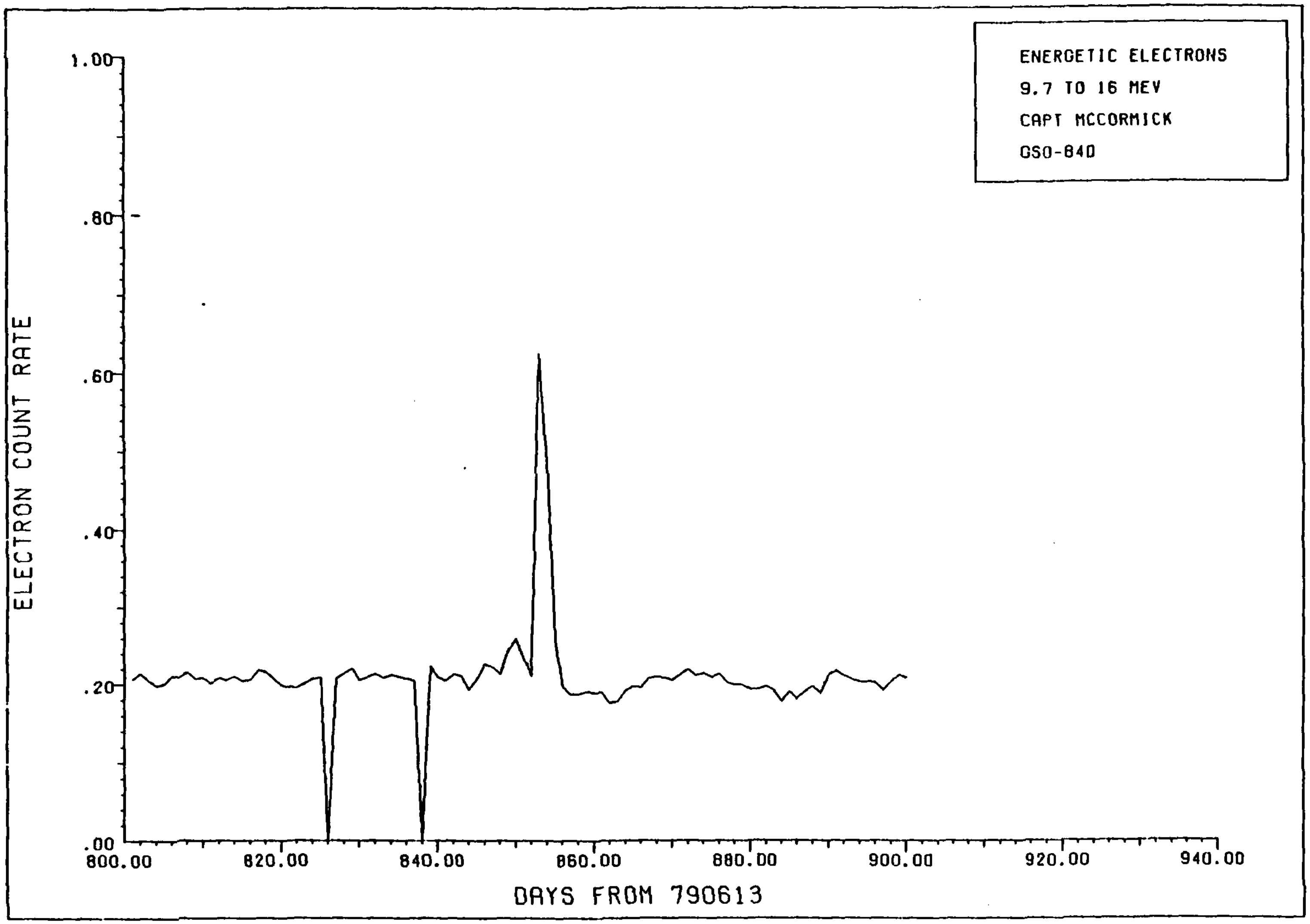

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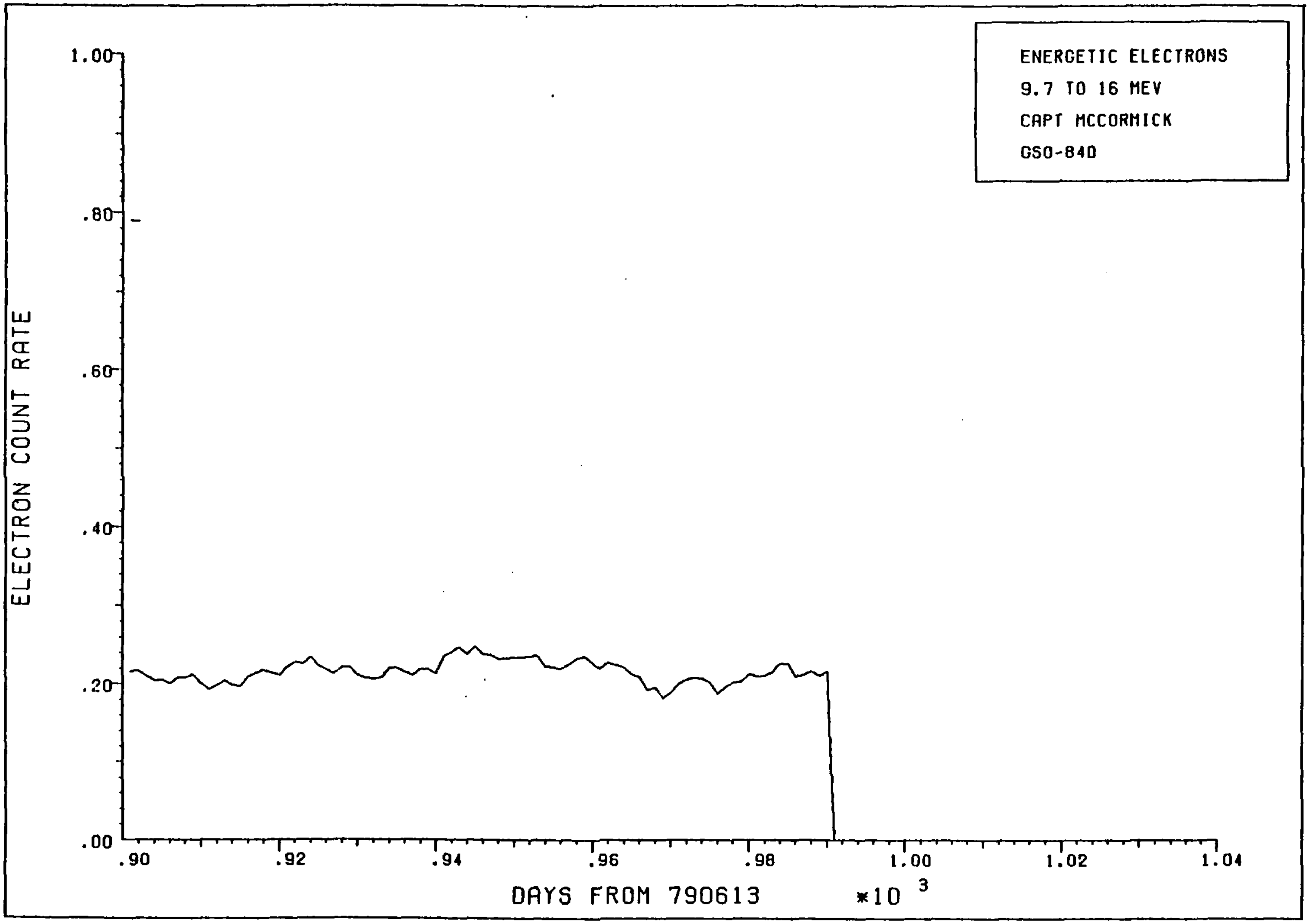

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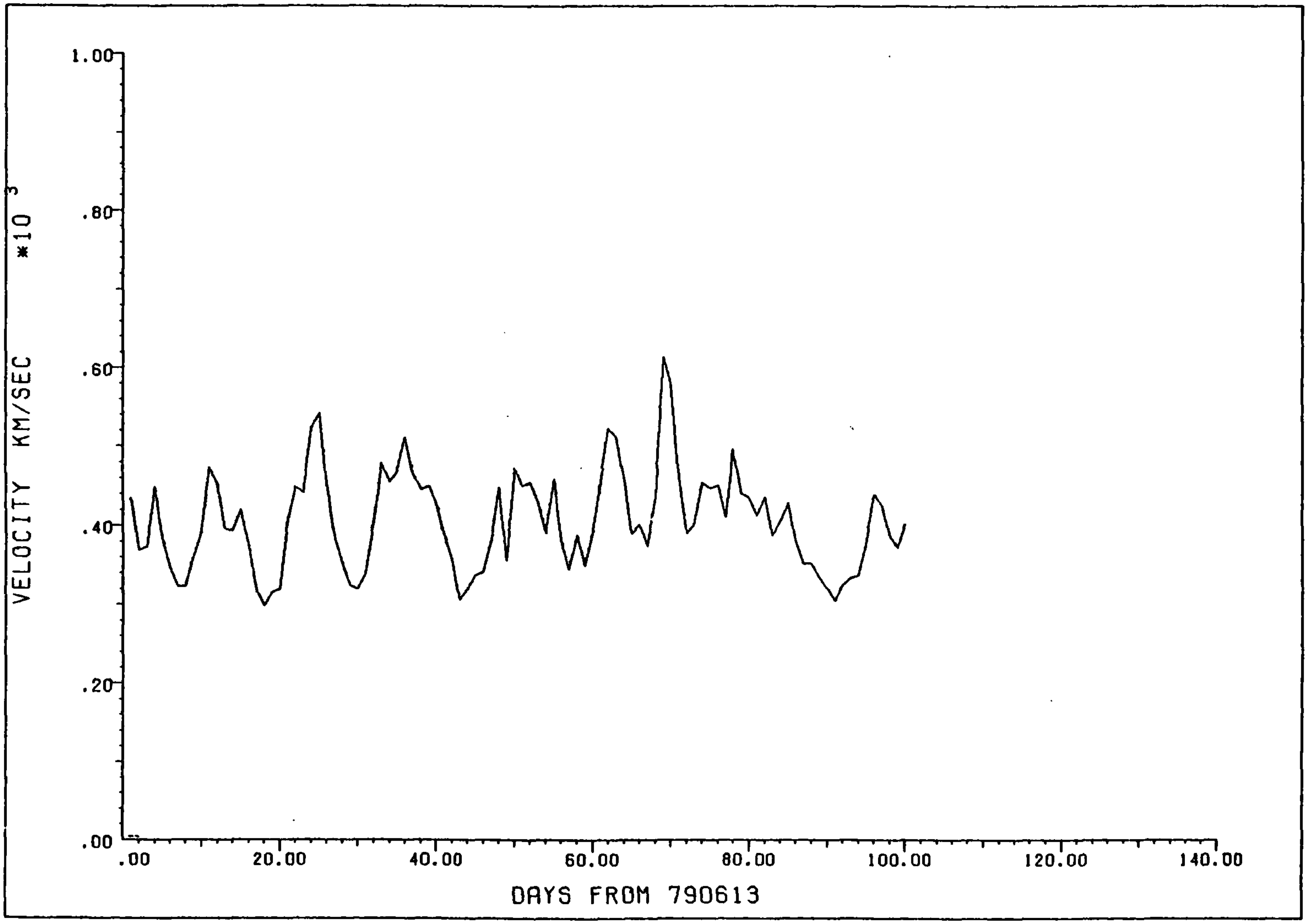

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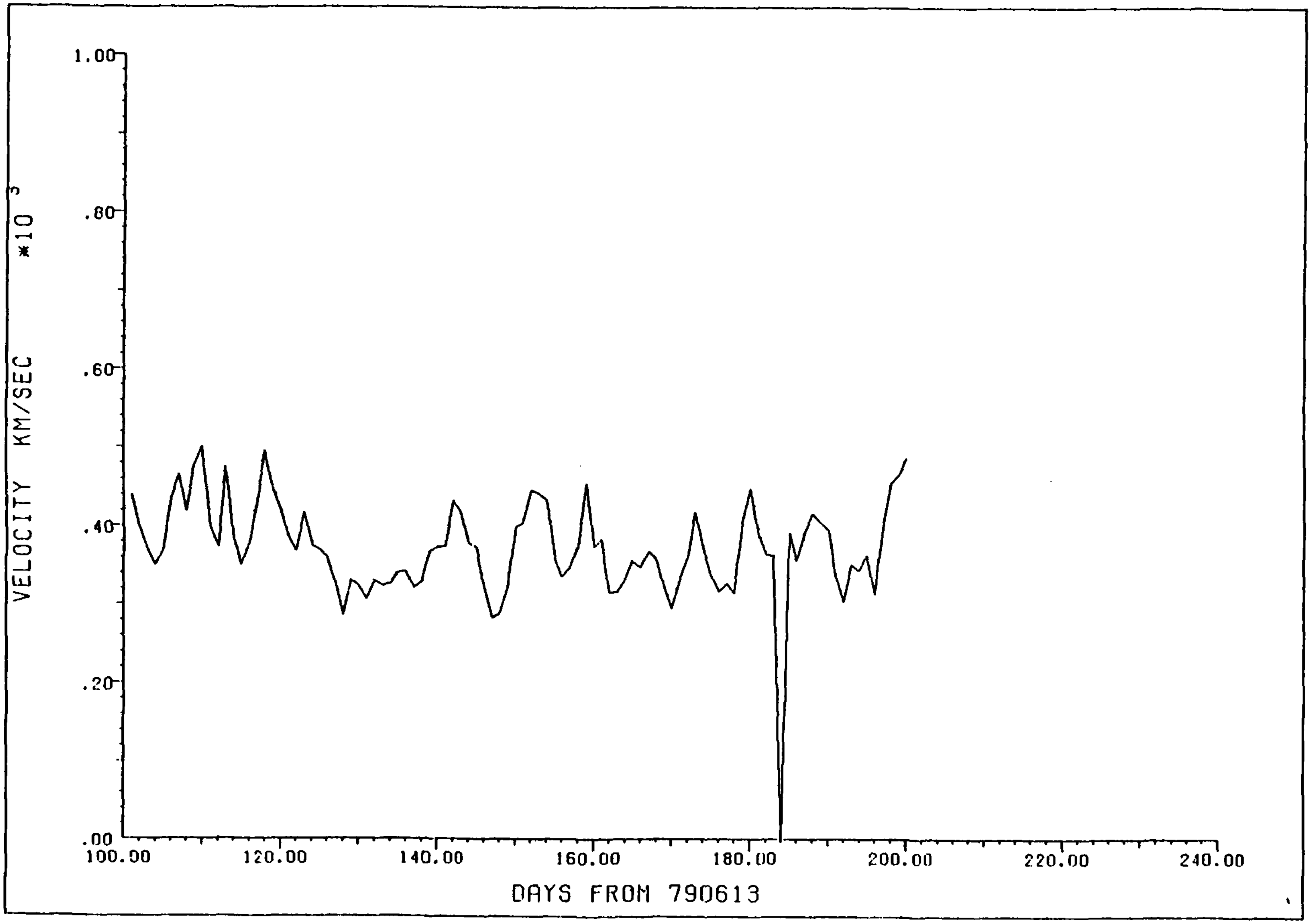

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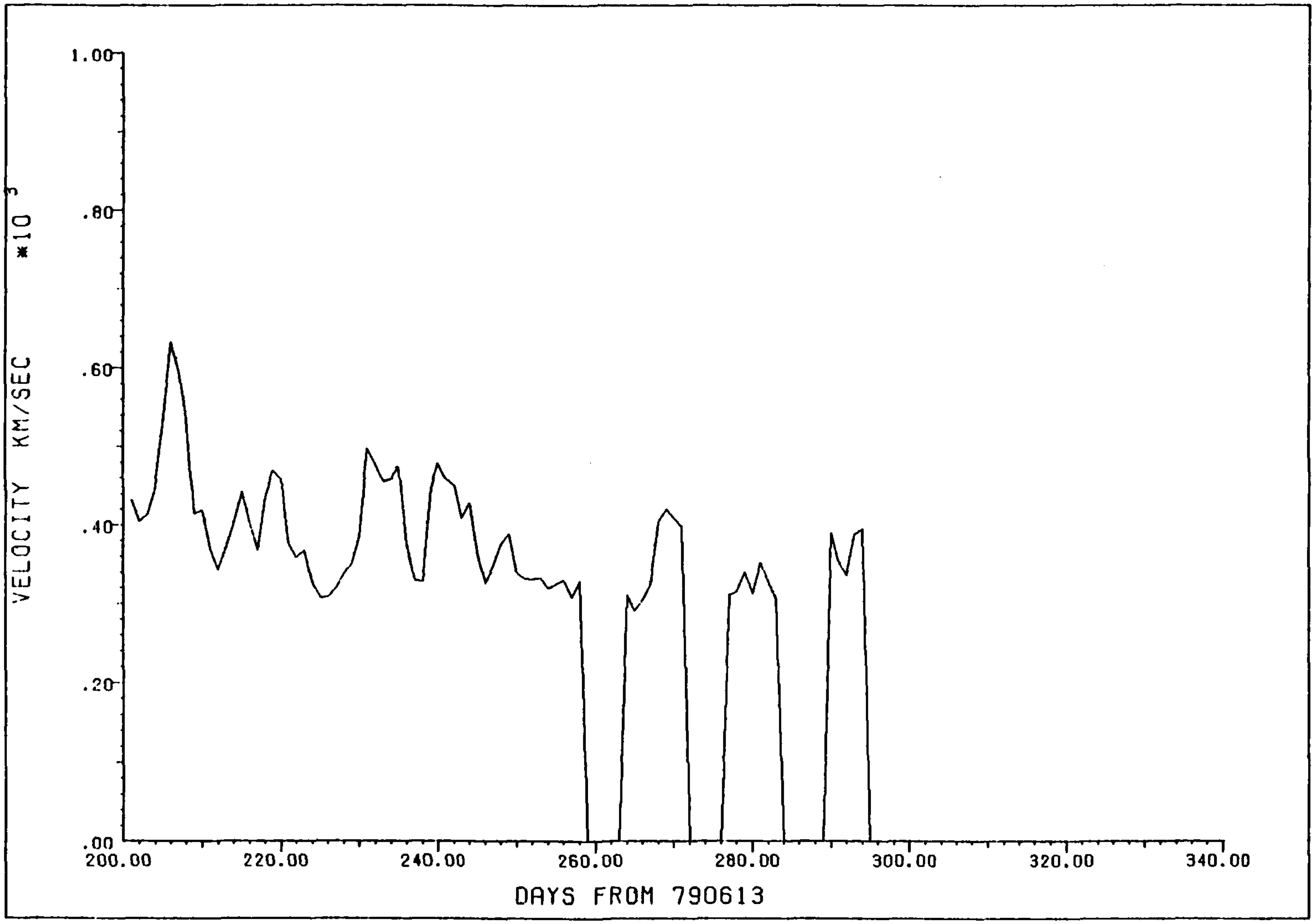

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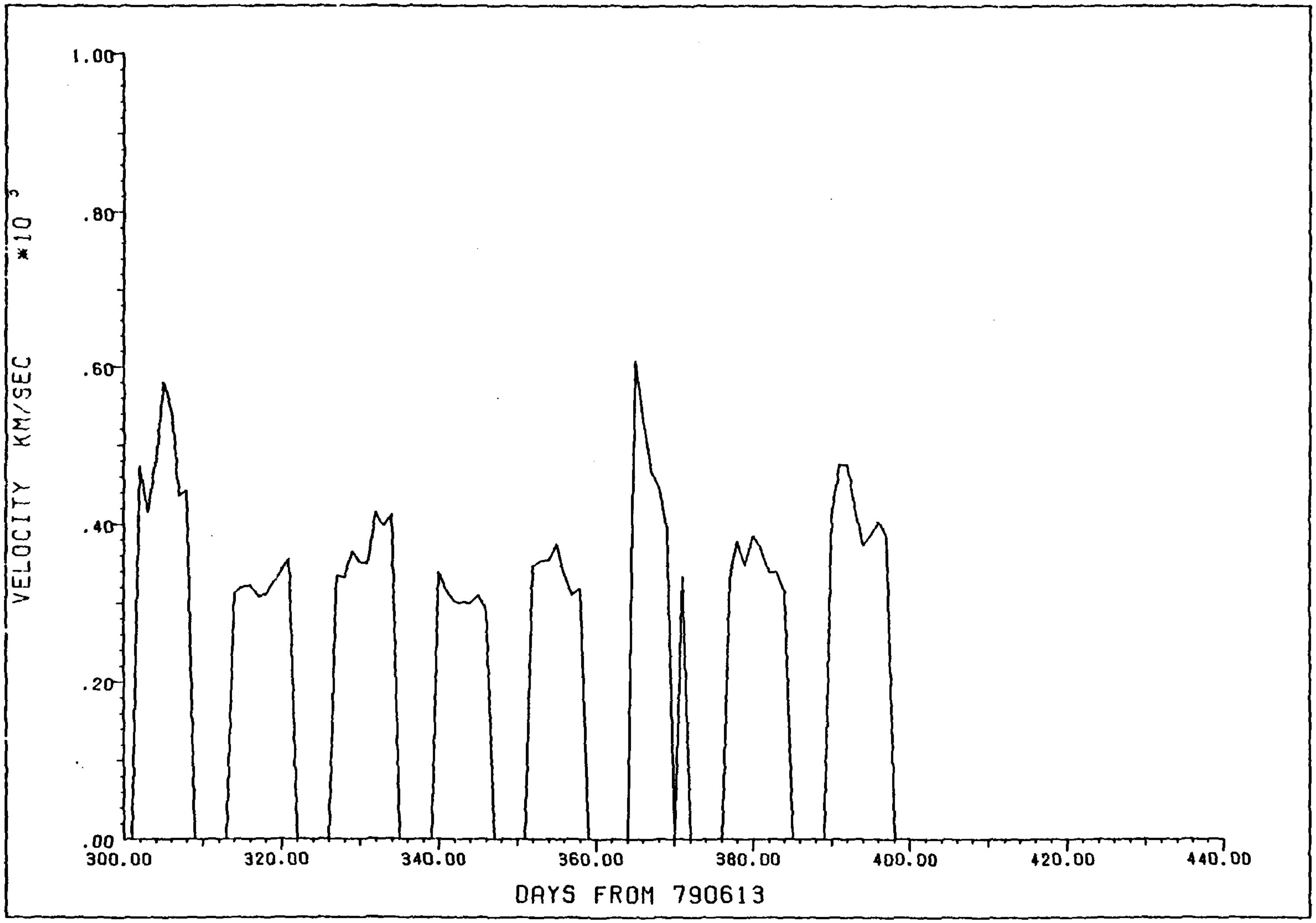

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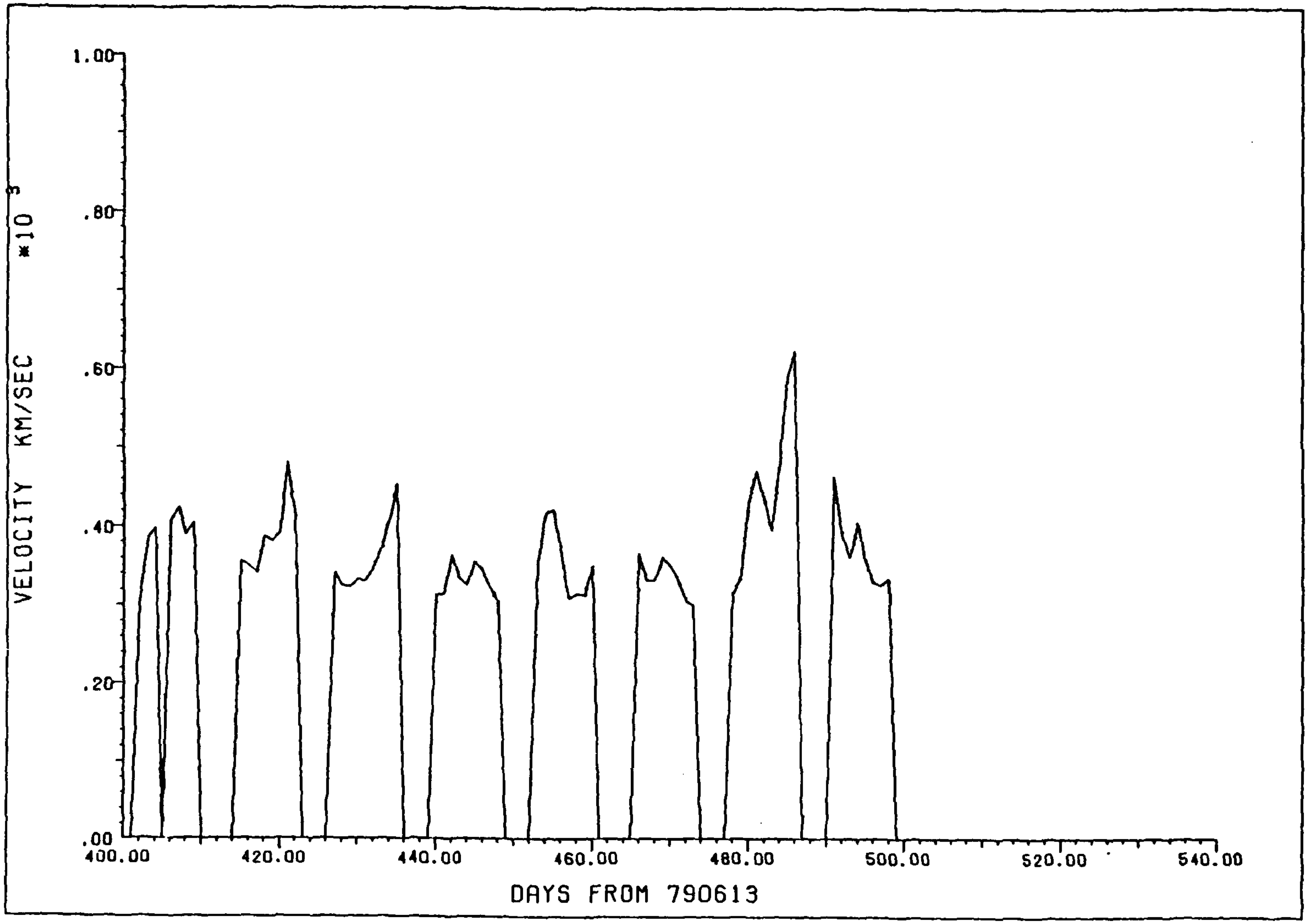

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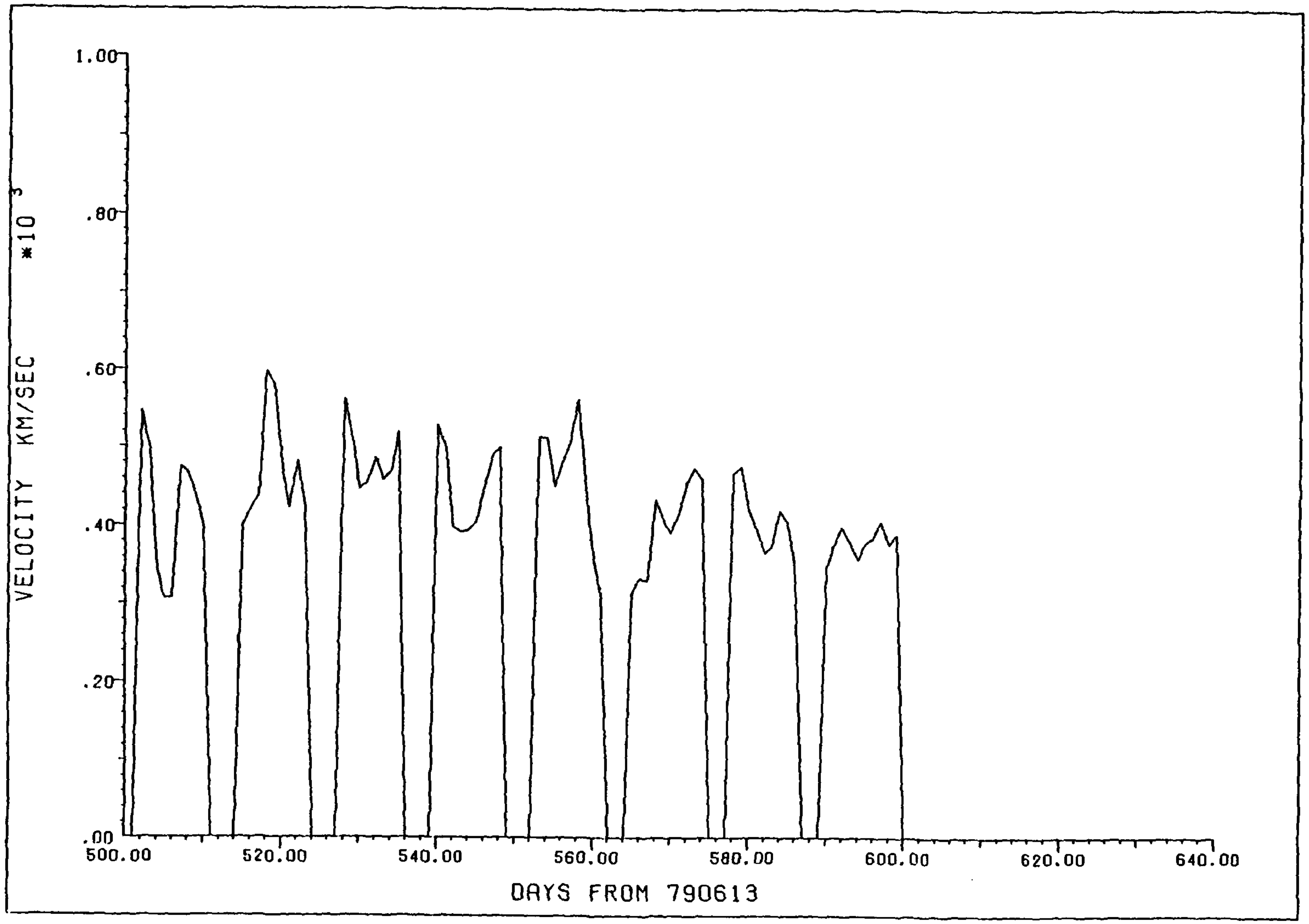

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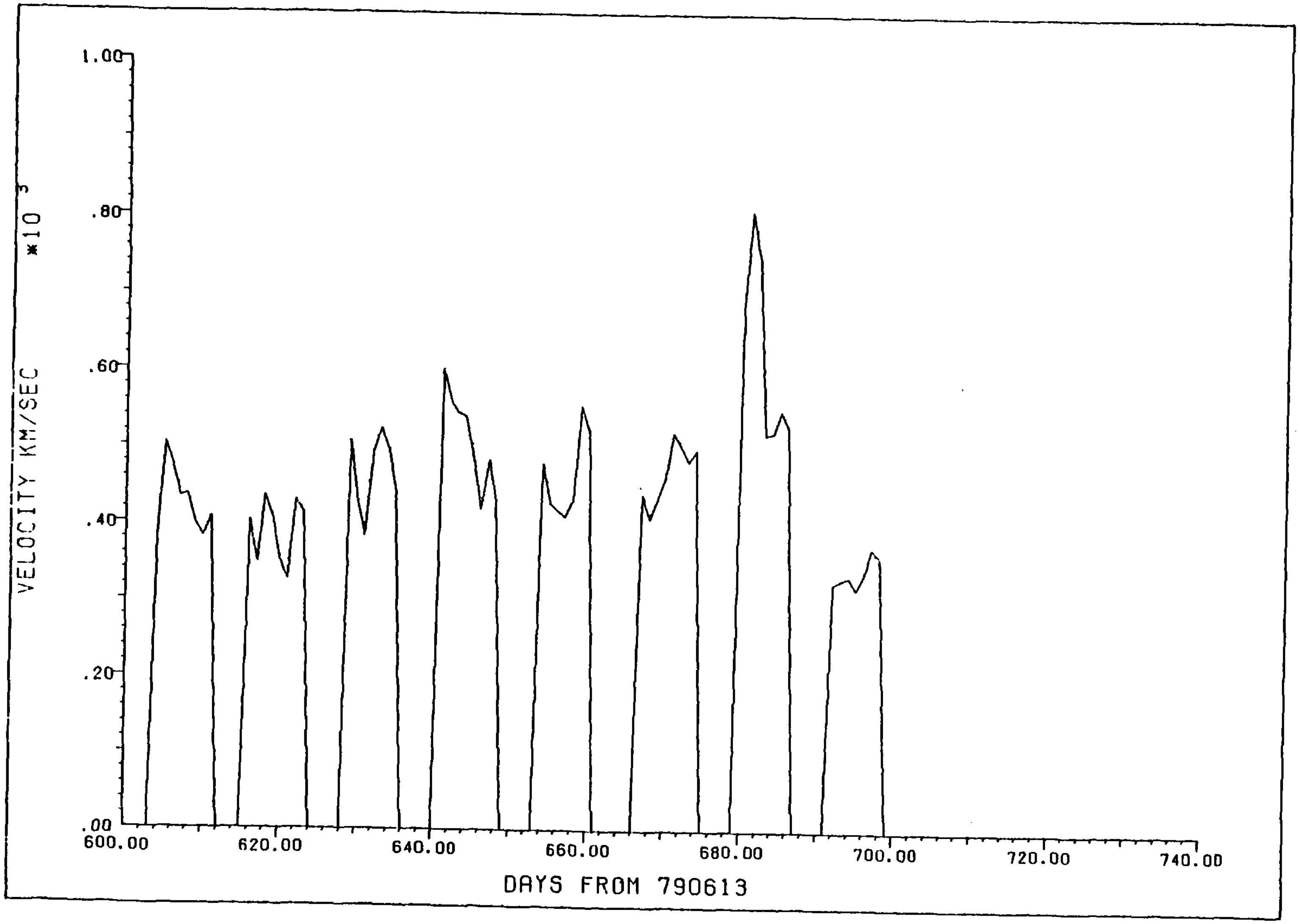

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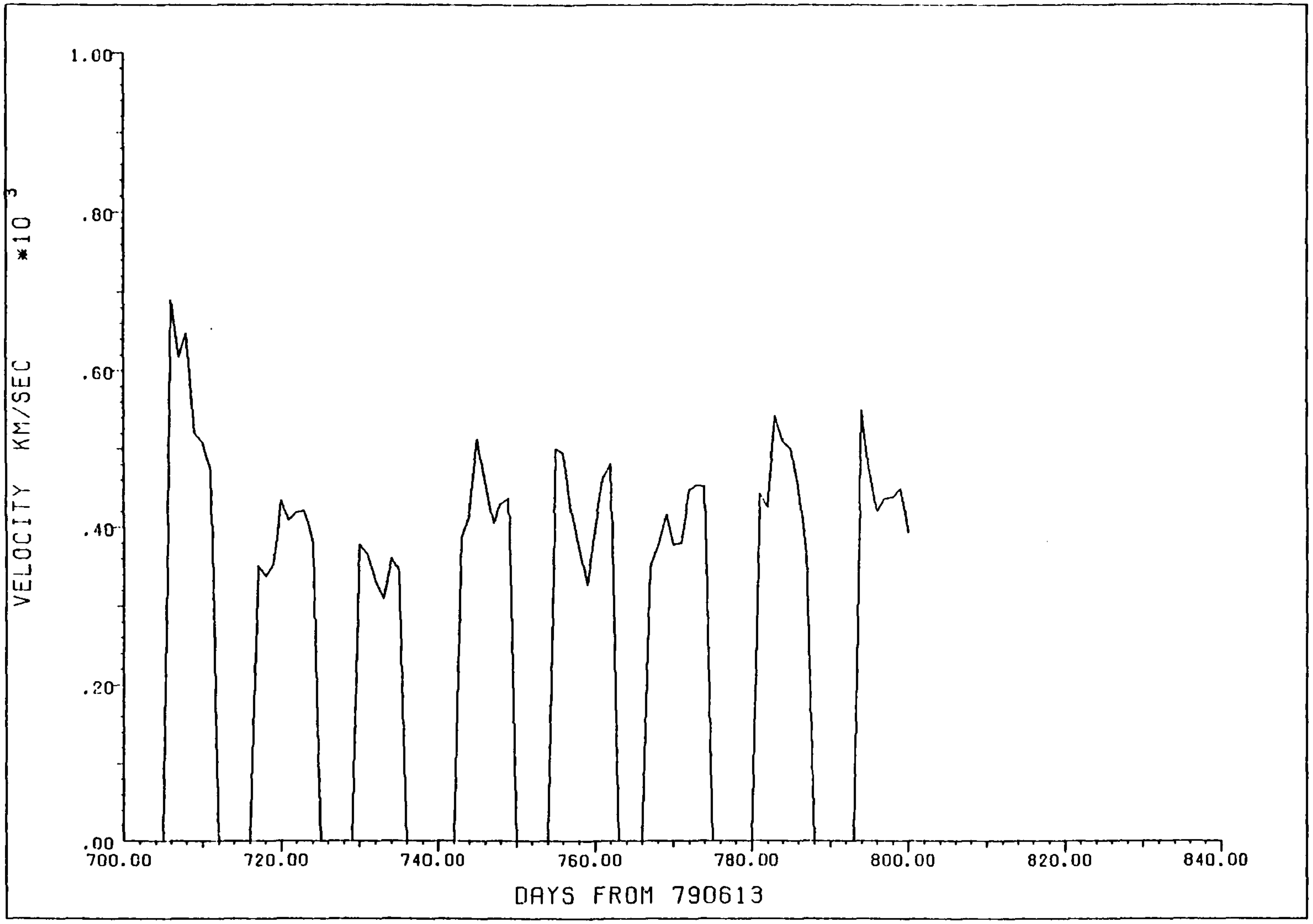

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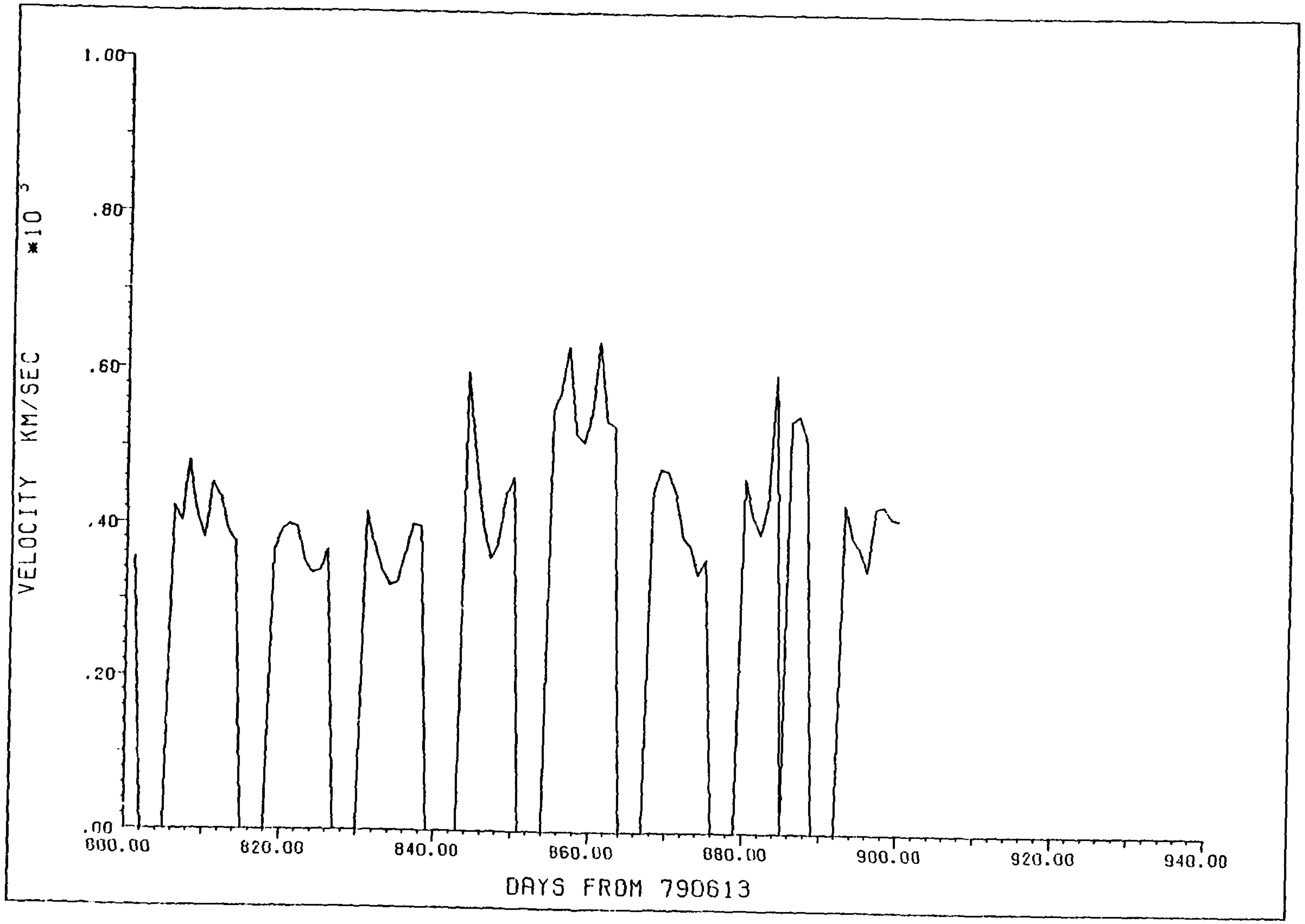

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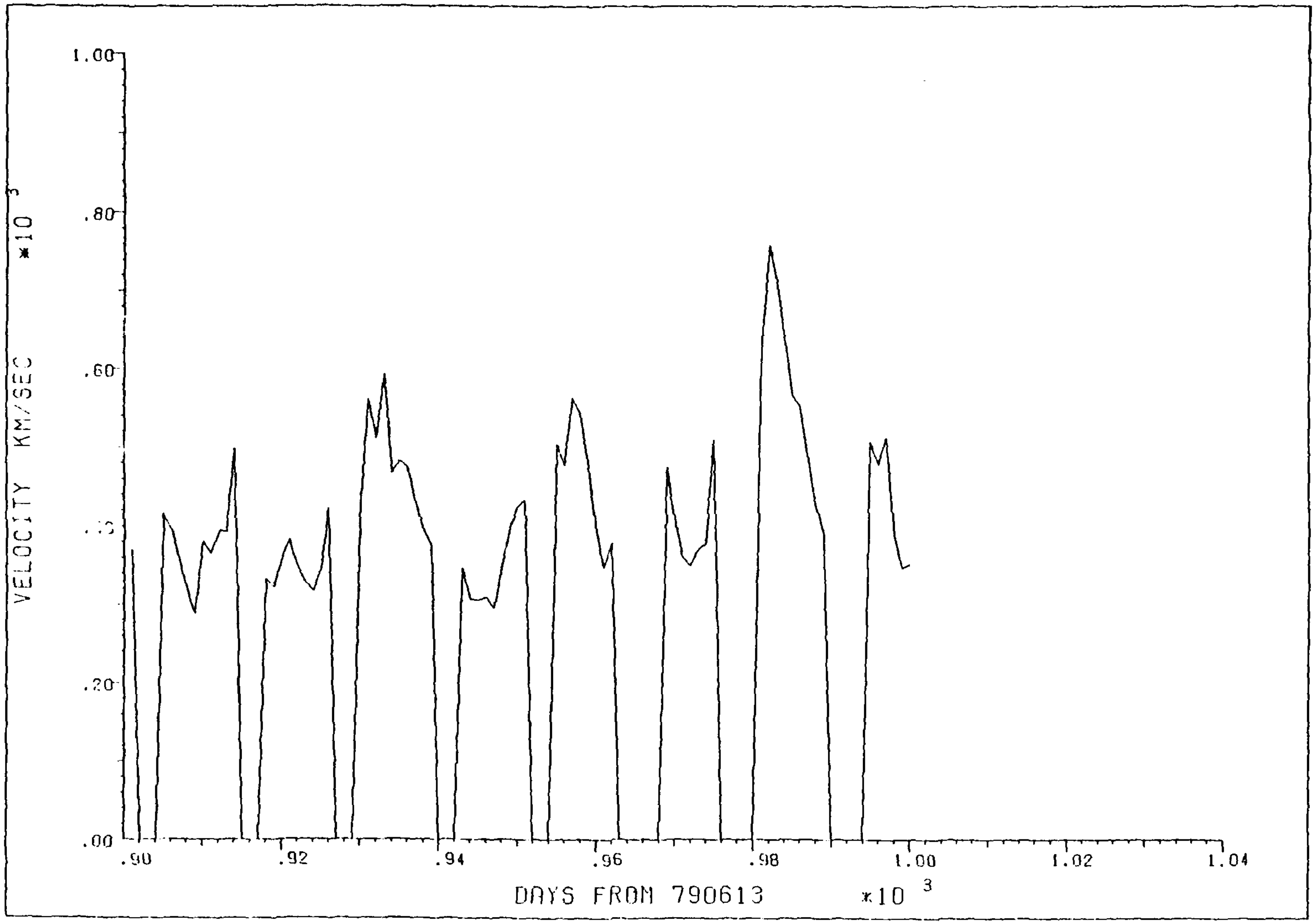

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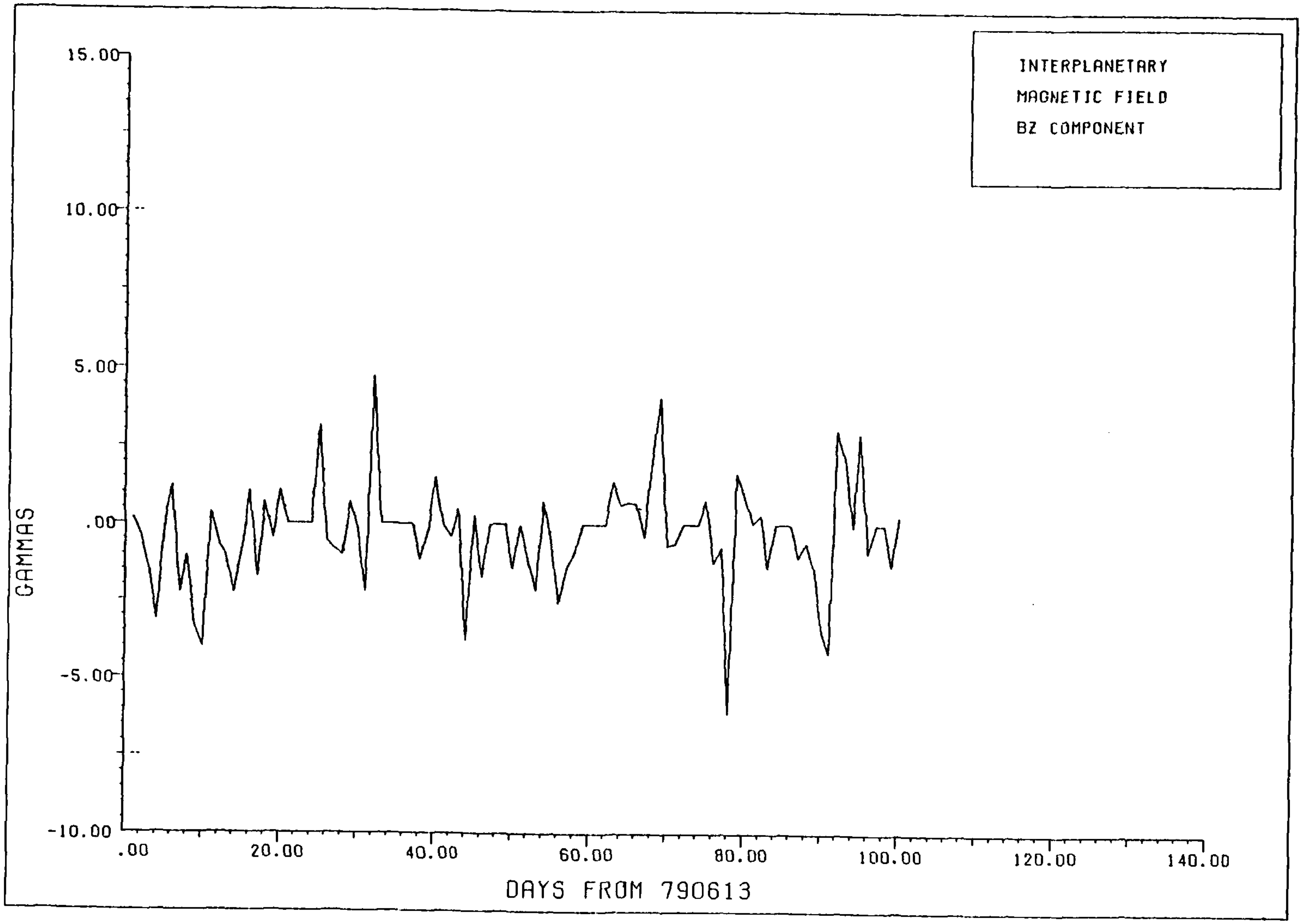

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VITA

Captain Douglas I. McCormick was born on 20 February 1955 in Central City, Nebraska. He graduated from high school in Littleton, Colorado in 1973 and entered the University of Northern Colorado, Greeley, Colorado. In June 1977, he graduated from UNC with a Bachelor of Arts degree in Mathematics. Upon graduation, he received a commission in the USAF through the ROTC program. From 1977 to 1983 Captain McCormick served in several assignments in the Space Operations career field. Captain McCormick entered the School of Engineering, Air Force Institute of Technology, in May 1983.

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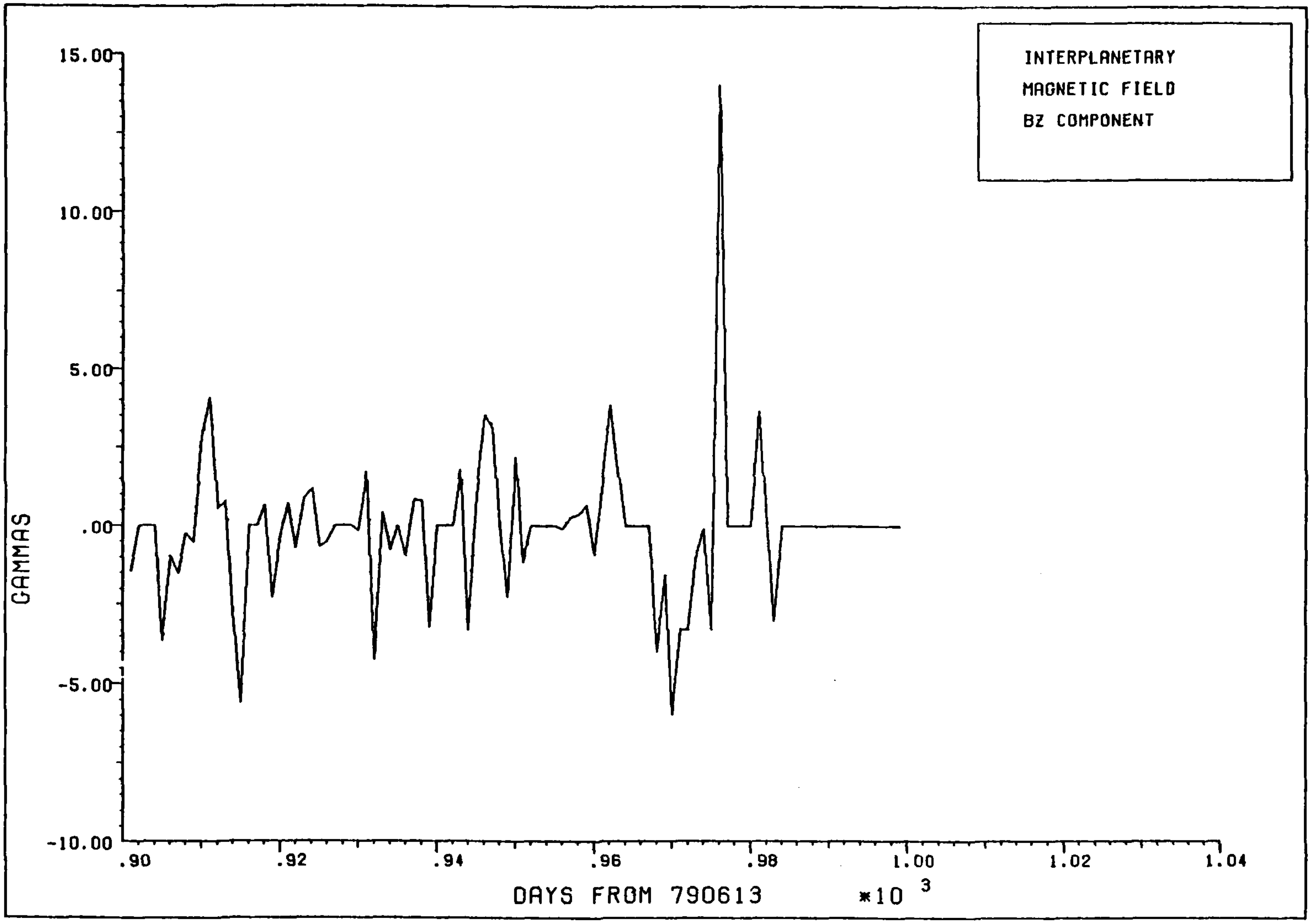

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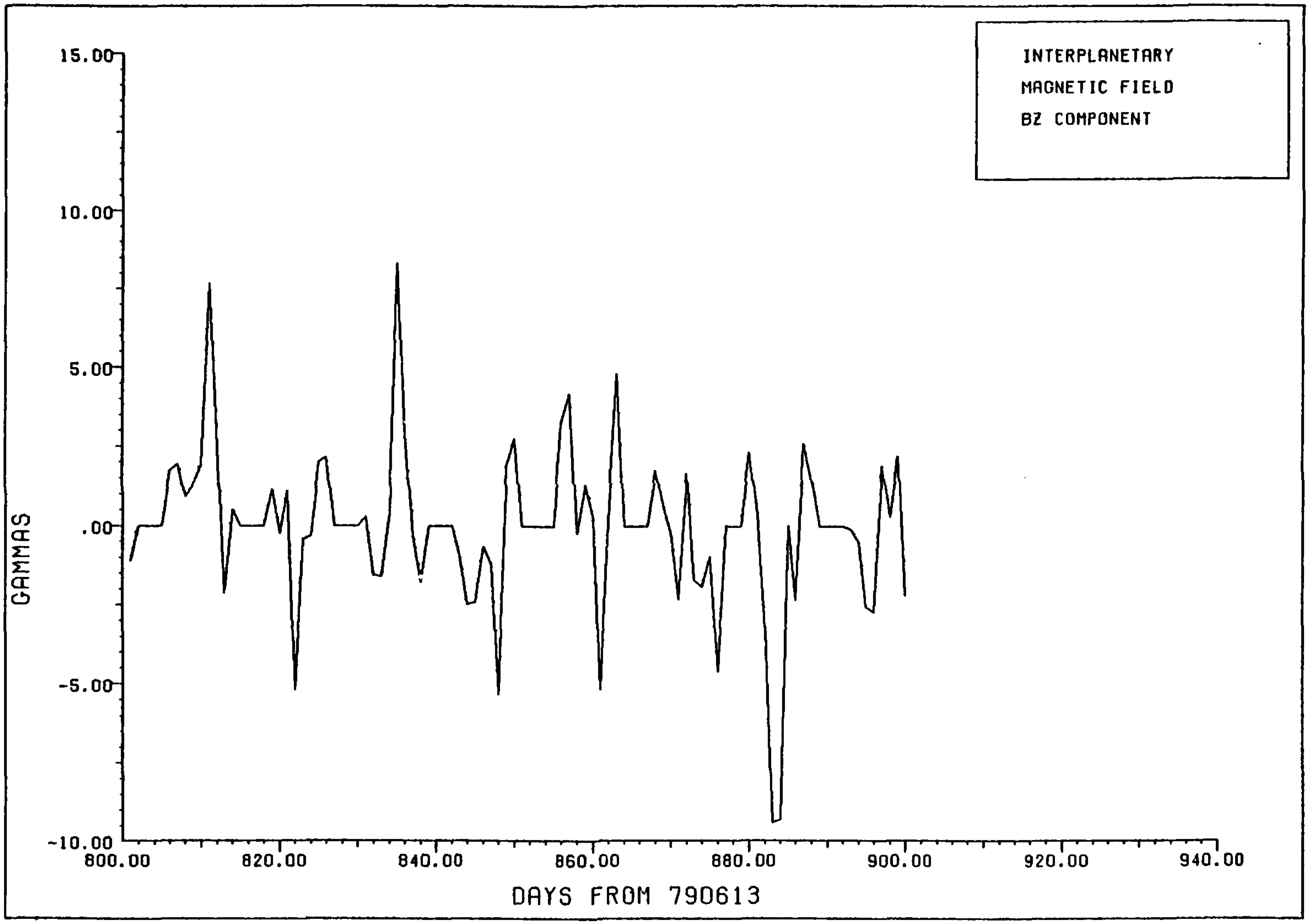

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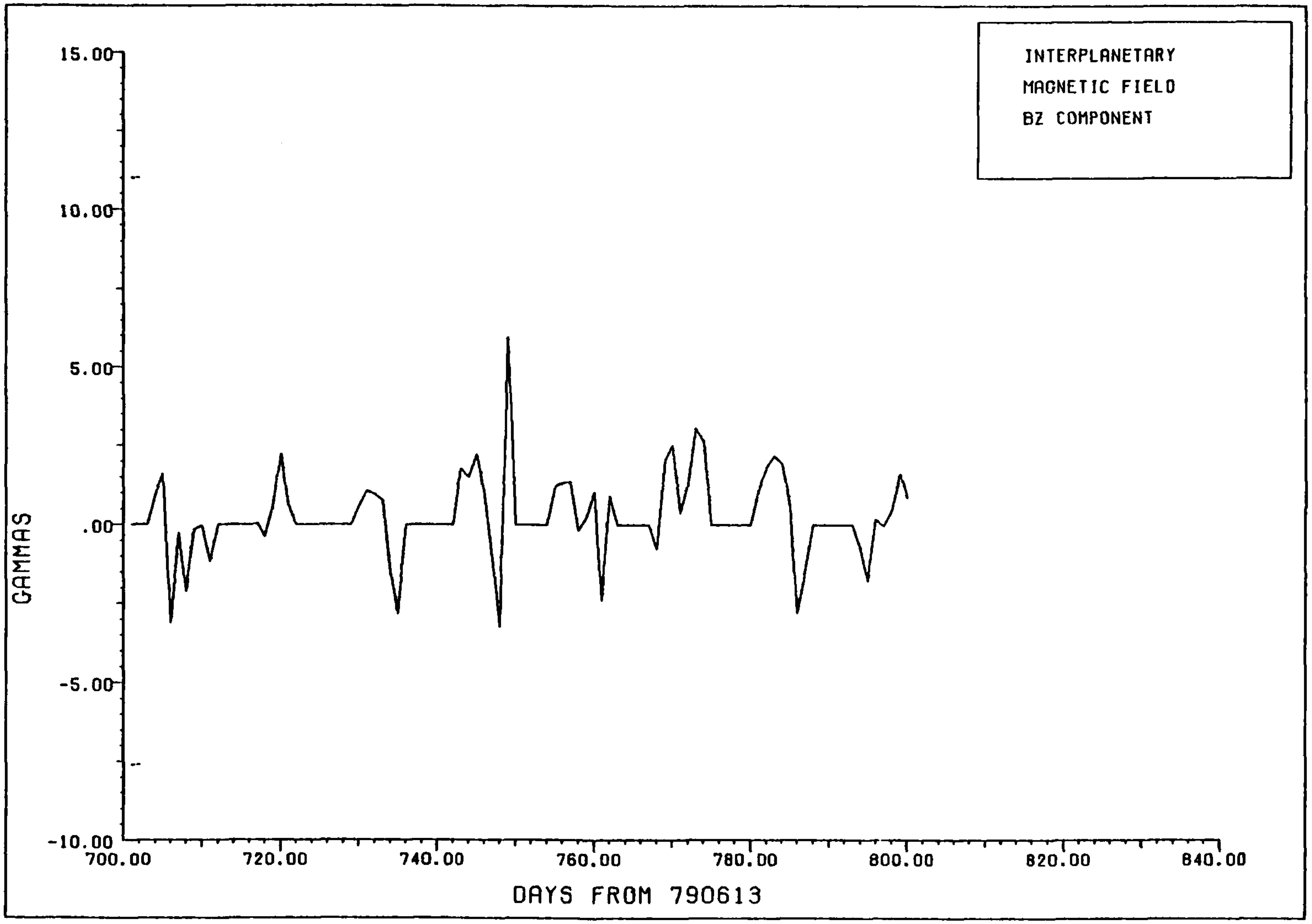

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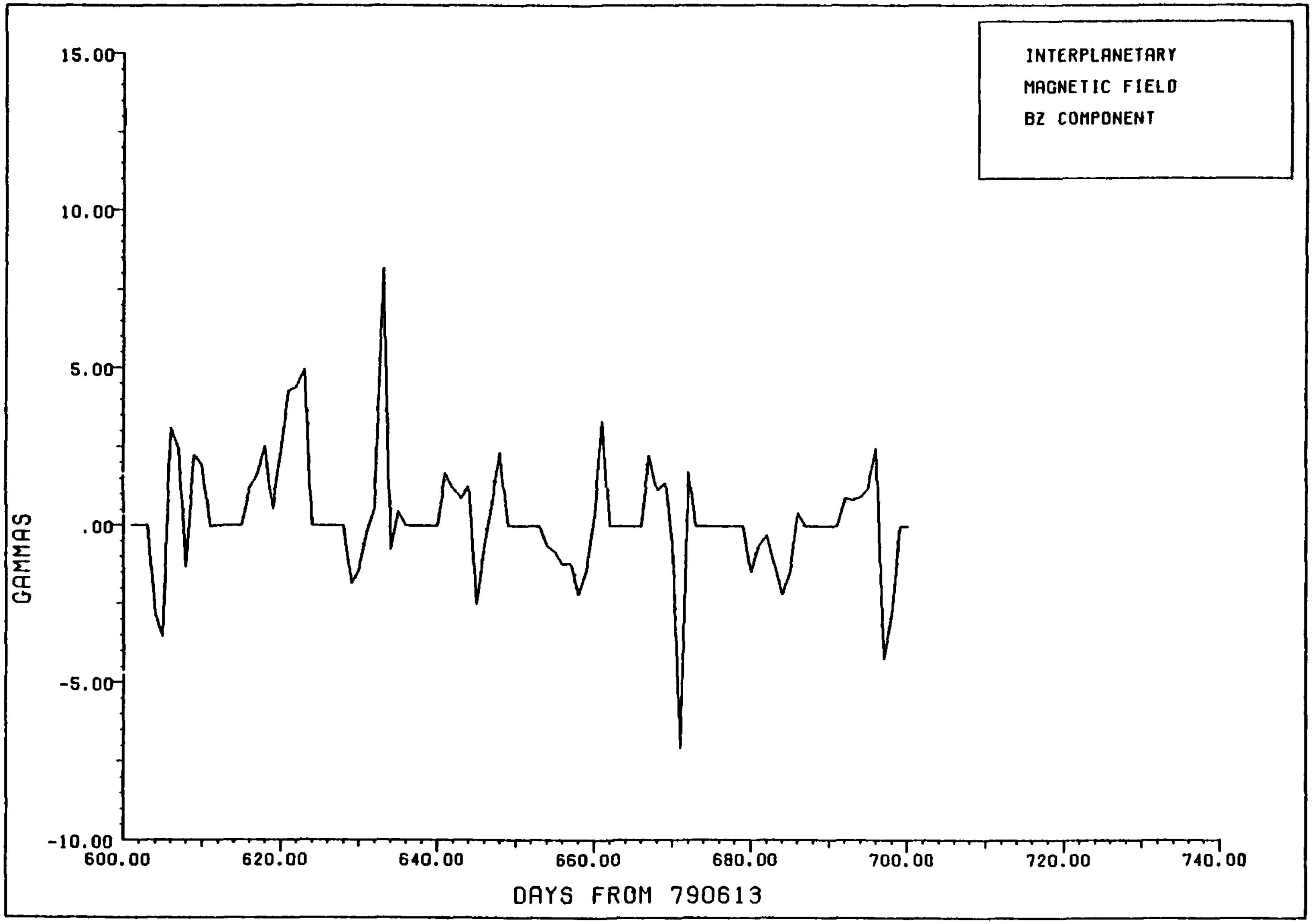

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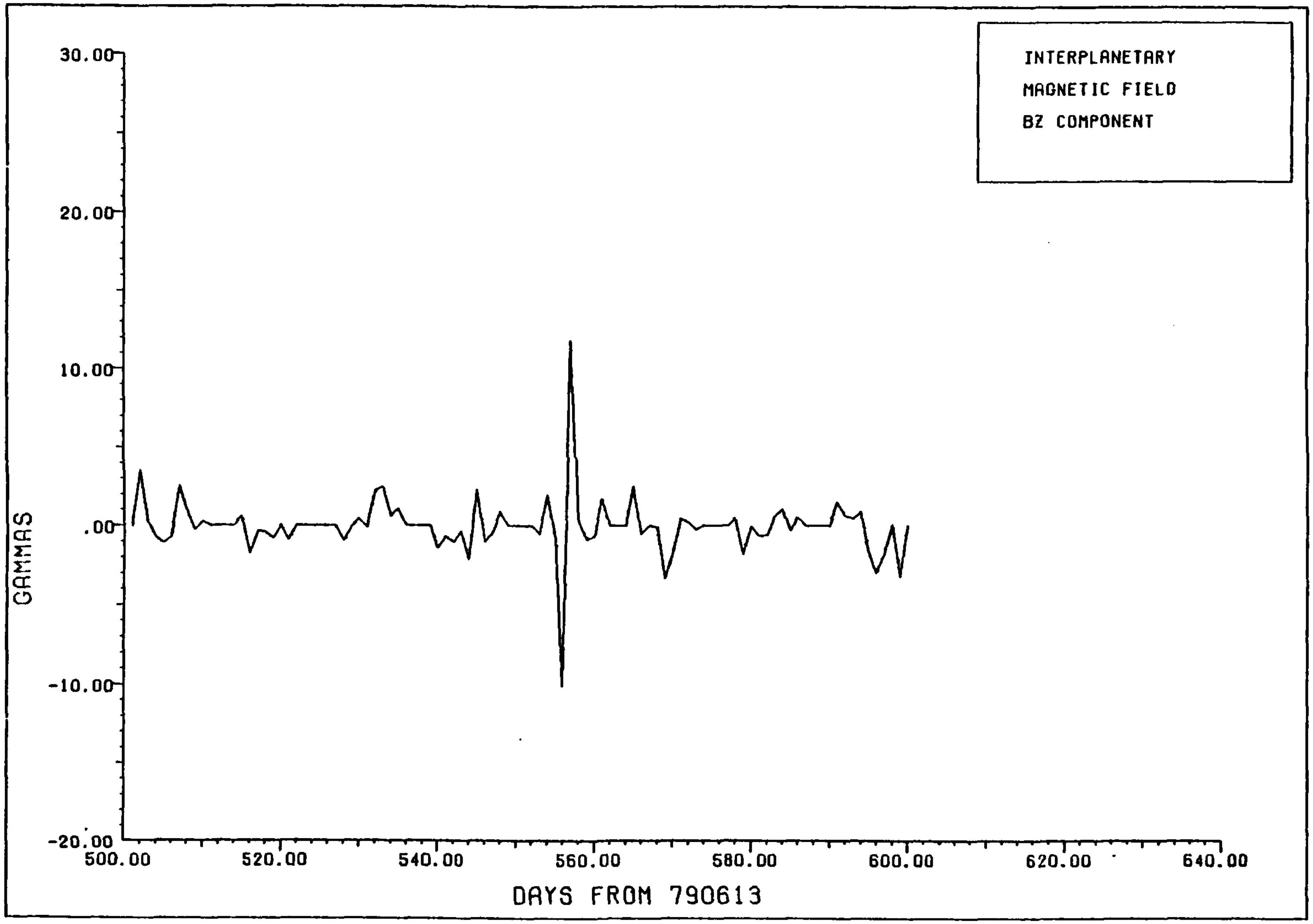

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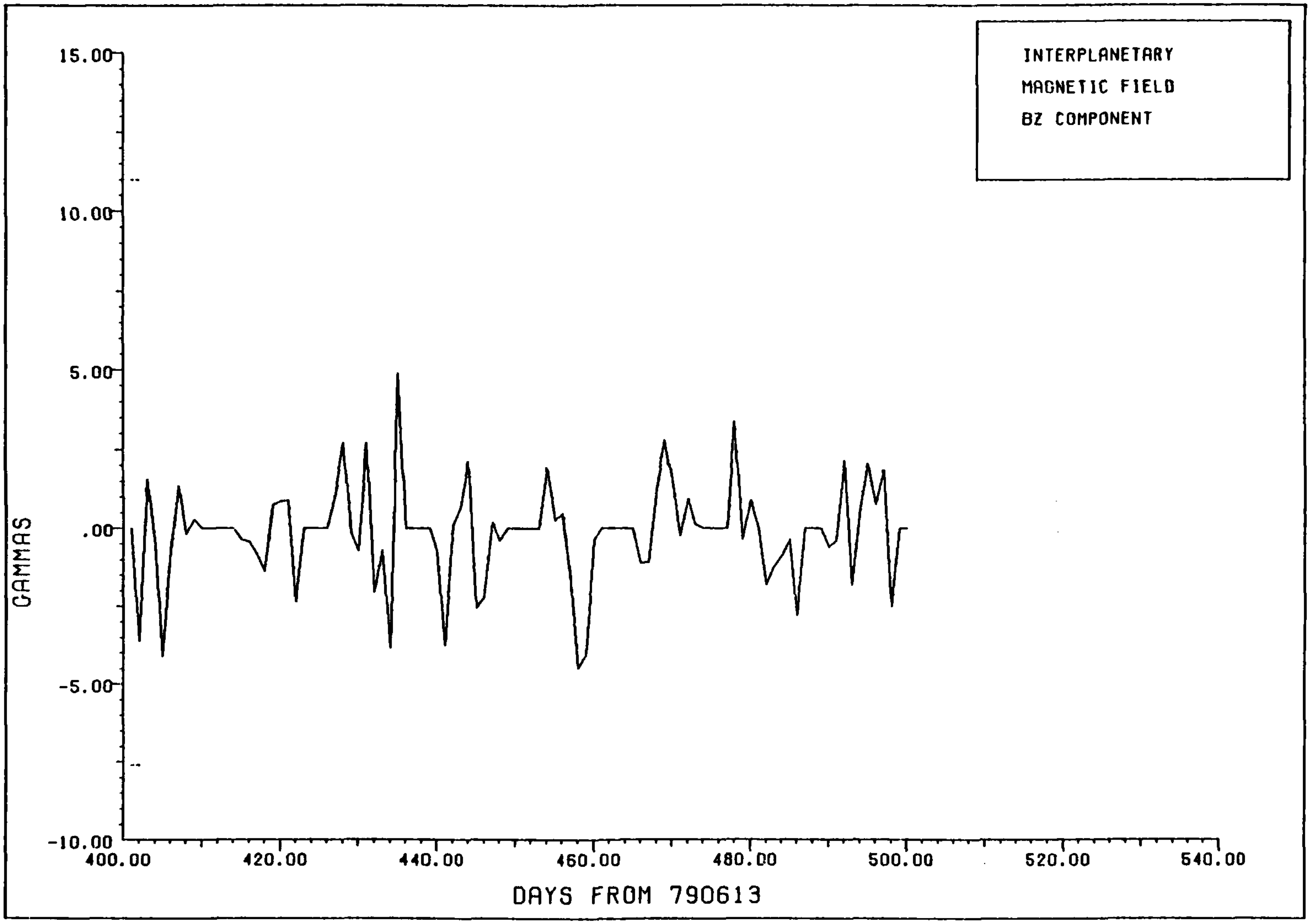

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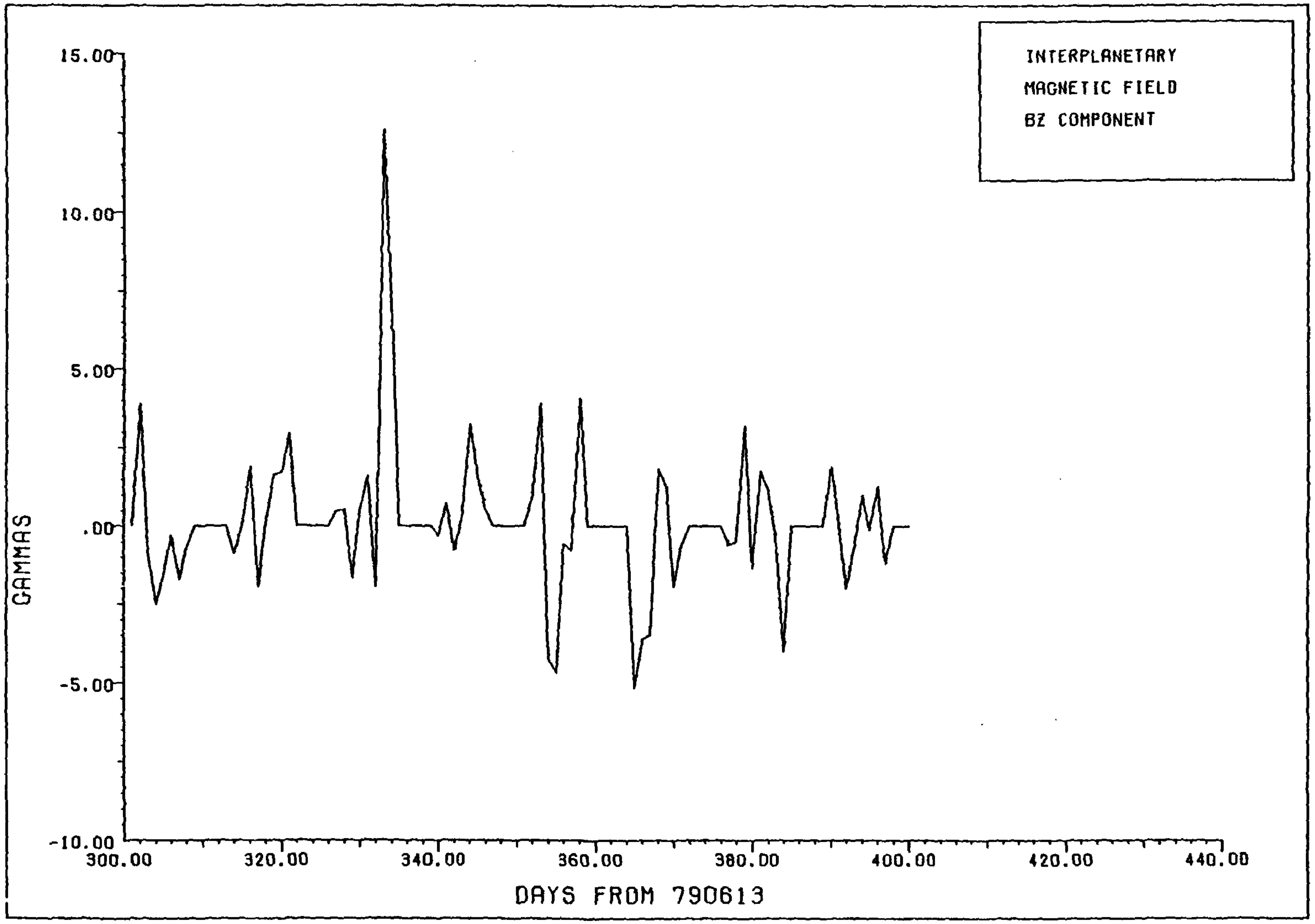

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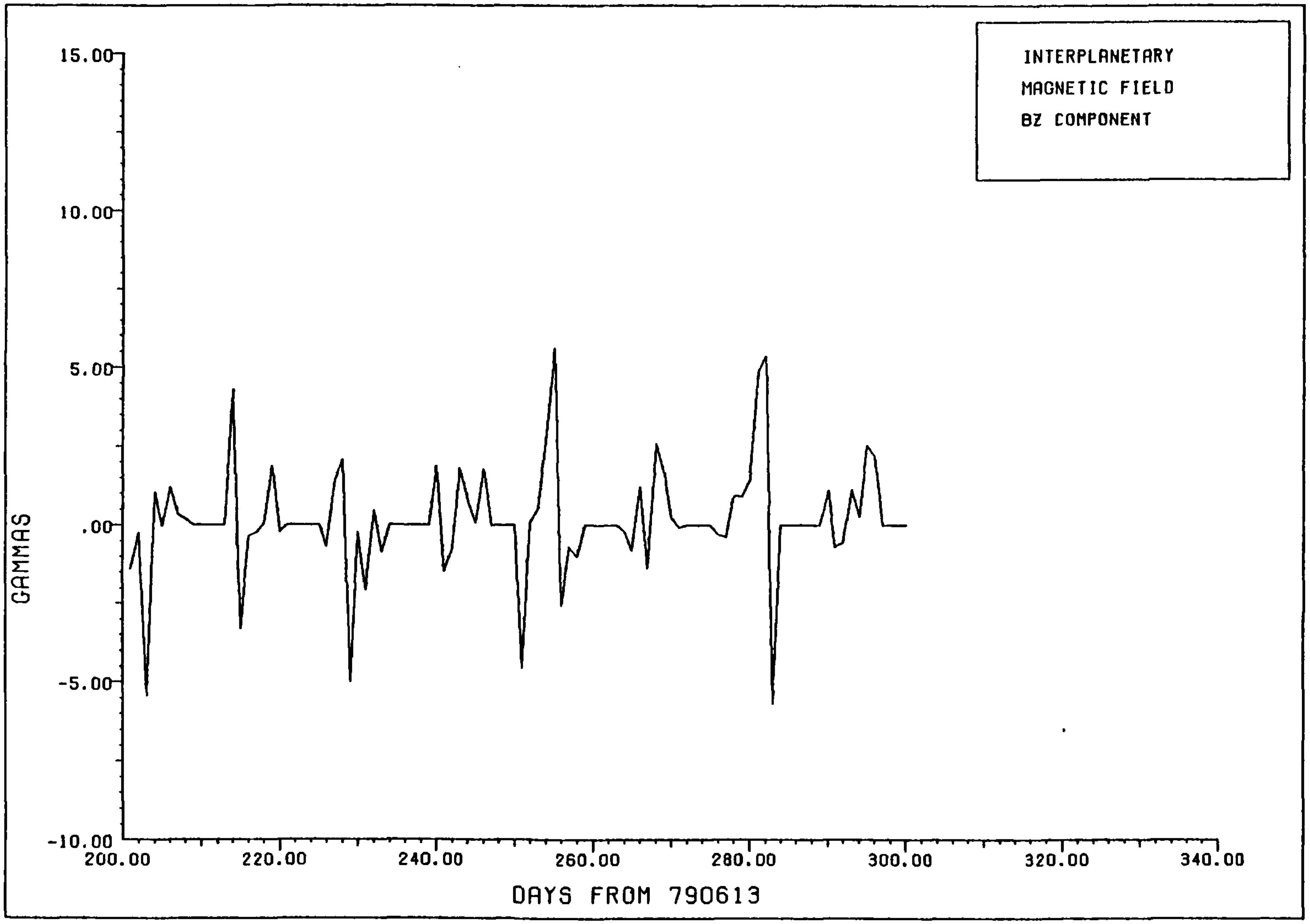

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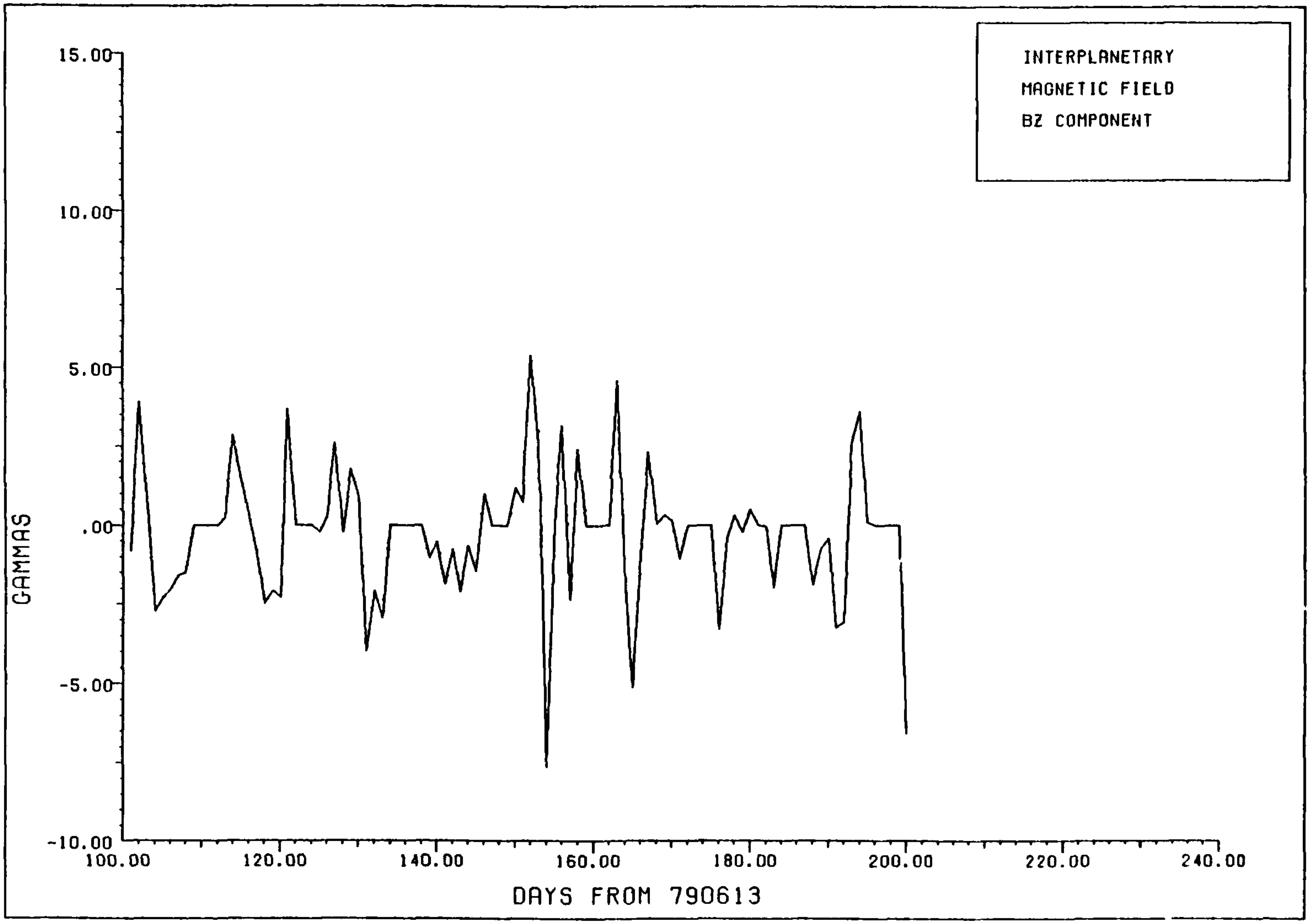

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18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
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19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Title: STATISTICAL ANALYSIS OF ENERGETIC ELECTRONS (1.2-16 MeV) AT GEOSYNCHRONOUS ORBIT

Thesis Chairmen: James Lange, Major, USAF
Joseph Coleman, Lieutenant Colonel, USAF

Approved for public release: IAW AFR 190-17.
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This investigation examined the relationship between energetic electrons (1.2-16 MeV) at geosynchronous orbit and solar wind speed and Interplanetary Magnetic Field (IMF) effects. Electron flux data for a three year period, June 1979 to April 1982, came from DOD spacecraft 1979-053 in geosynchronous orbit. This data was compared statistically with solar wind and IMF data measured by other spacecraft located in the solar wind. Statistical techniques employed included graphical plotting, descriptive statistics, correlation analysis, analysis of variance, and discriminant analysis.

Results from this study used daily average values and indicate clear differences in behavior between 1.2 to 6.6 MeV electrons and 6.6 to 16 MeV electrons. Electron flux in the energy ranges of 1.2-1.8 MeV, 3.4-4.9 MeV, and 4.9-6.6 MeV showed generally strong correlation with each other. Electron flux in the energy ranges of 6.6-9.7 MeV and 9.7-16 MeV also showed strong correlation with each other, but not to the three lower energy channels. There was a weak positive correlation between electron flux below 6.6 MeV and solar wind speed, after one and a half to two days passage. There was a weaker, negative correlation between solar wind speed and electron flux between 6.6 and 16 MeV. There was no meaningful correlation between electron flux at any energy level and IMF effects. These findings suggest that whatever processes affect electron fluctuations below 6.6 MeV are different from those for electrons above 6.6 MeV.

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